MAR/APR 1983 VOL. 5 NO. 2

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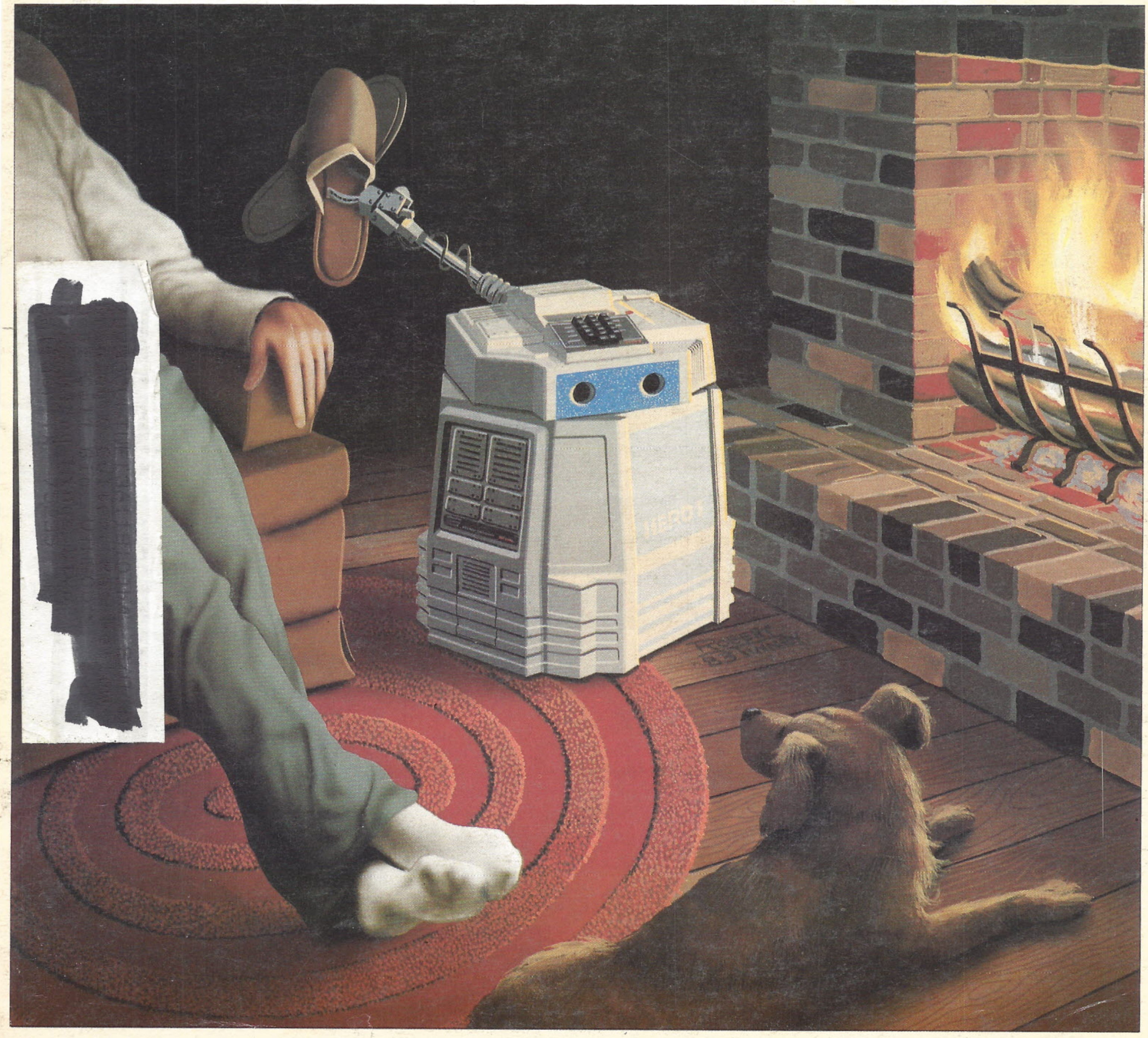
THE JOURNAL OF INTELLIGENT MACHINES

ROBOTICS AGE™



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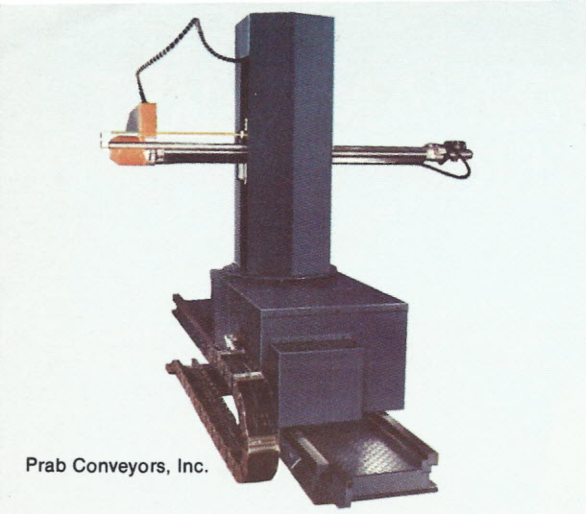
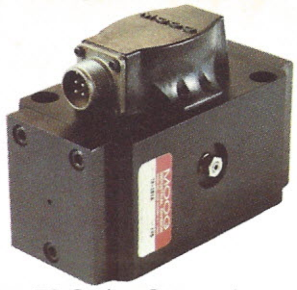
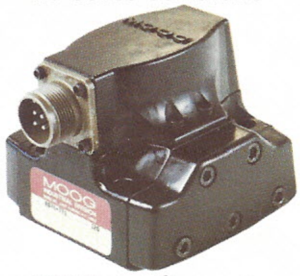
CIRCLE 20



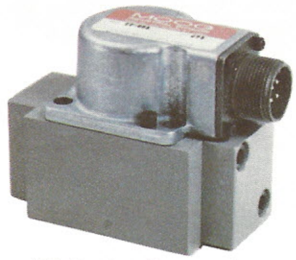
Moog Servovalves



78 Series Servovalve



760 Series Servovalve



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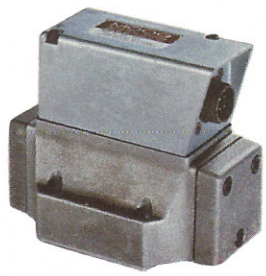

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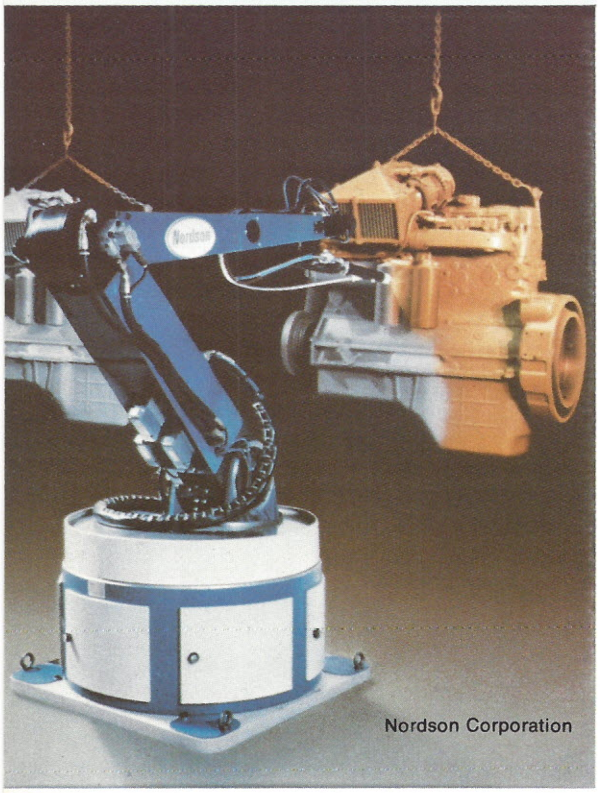

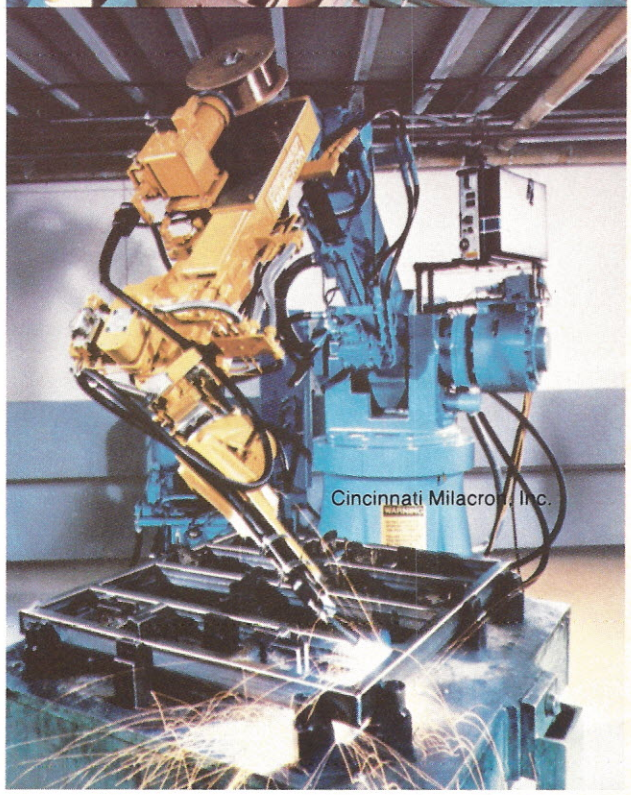

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CIRCLE 18

Calendar

APRIL

April 13-21, 1983. 13th International Symposium on Industrial Robots/Robots 7. McCormick Place and Conrad Hilton Hotel, Chicago, Illinois. Contact: Public Relations Department, SME, One SME Drive, PO Box 930, Dearborn, Michigan 48128. Phone: (313) 271-1500.

The theme of Robots 7 is "Robotics: The Emerging Challenge." This technical program is composed of 18 conference sessions, three basic sessions, and four special forums. Topics include robot design, materials handling, design and construction of mobile robot systems, robot safety, vision research, and aerospace applications. The 1983 Joseph F. Engleberger Awards will be presented during the conference. Robots 7 is sponsored by Robots International of the Society of Manufacturing Engineers and the Robot Institute of America.

MAY

May 2-5, 1983. Test & Measurement World Expo. San Jose Convention Center, San Jose, California. Contact: Meg Bowen, Test & Measurement World Expo, 215 Brighton Avenue, Boston, Massachusetts 02134. Phone: (617) 254-1445.

This specialized conference and exhibition will cover the entire range of test, measurement, and inspection technology for the electronics industry. The 10 major programs are: Failure Analysis, EMI/ RFI Evaluation, Optical Inspection, Test Software, Subassembly/System ATE, Component Test, VLSI Test, Microelectronics Measurement, Test Instruments, and Communications/ Microwave Test.

May 2-5, 1983. International Tool & Manufacturing Engineering Conference and Exposition. Cobo Hall, Detroit, Michigan. Contact: Public Relations Department, SME, One SME Drive, PO Box 930, Dearborn, MI 48128. Phone: (313) 271-0777.

The theme of this four day convention is "Meeting New Challenges through Innovative Technologies." The exposition will feature demonstrations of new-generation machine tools, computer-controlled manufacturing systems, and a wide array of metalworking equipment and engineering services. Over 450 exhibitors are expected to display more than 1,000 different items.

May 9-12, 1983. Sixth Princeton Conference on Space Manufacturing. Princeton University, Princeton, New Jersey. Contact: The Space Studies Institute, Box 82, Princeton, New Jersey 08540.

Sponsored by the Princeton University Conference and the Space Studies

Continued on page 22

THE JOURNAL OF INTELLIGENT MACHINES

ROBOTICS AGE™

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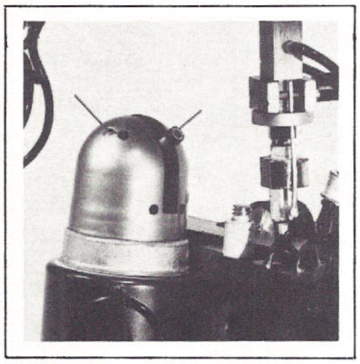

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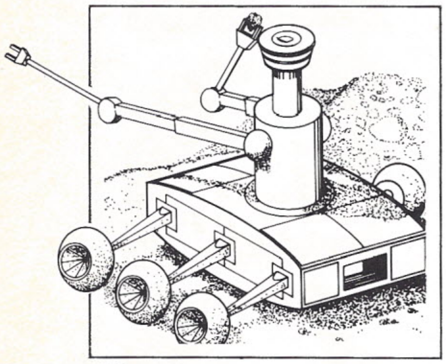

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EDITORIAL

FEATURES

DEPARTMENTS

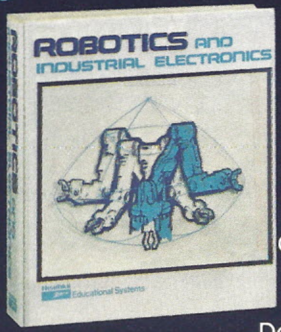
About The Cover: Cover artist Robert Tinney has taken the theme of Heathkit's new Hero-I robot and applied it to a fanciful, real-world situation of the next few years. While his master's dog looks on, our hero is seen accomplishing a domestic task. Never mind that his sensors are not yet developed enough to see the slippers it holds. We'll allow artistic license to take liberties with the real lifting and grasping capabilities of the machine. Robert's dramatic point is made—Hero marks one milestone in the development of widely used robotic systems.

INTRODUCING the world's first, affordable teaching robot...

HERO 1 the most sophisticated microprocessor-controlled device since the microcomputer.

HERO 1 is a completely self-contained, electro-mechanical robot capable of interacting with its environment. Controlled by an on-board, programmable computer, it has electronic sensors to detect light, sound, motion and obstruction in its path.

Capable of seven axes of motion, the robot can be programmed to pick up small objects with its arm. It will also speak in complete sentences, using its voice synthesizer.



Remarkable though the robot is, its companion Robotics Education Course is an even more significant "first." It provides a thorough understanding of robot technologies, including robotics programming. Course features self-test unit reviews, experiments and final exam. Designed to be used with HERO 1, this 1200 page course is the most complete introduction to robotics available today.

HERO 1 is a computer on wheels. HERO 1 uses a 6808 microprocessor that controls 13 functions and sense boards. Its on-board processor can take it through complex maneuvers. The programming process is straightforward with provision for step-by-step debugging, enhancement and other corrections.

HERO 1 senses include: sound detection (frequency range 200-5000 Hz); light detection; ultrasonic ranging; ultrasonic motion detection; speech synthesis; and real time, four year calendar clock.

A completely mobile platform robot, HERO 1's motion abilities permit head rotation and arm rotation of 350,° shoulder rotation of 150,° arm extension of 5 inches, wrist pivot of 180° and wrist rotation of 350.° Gripper will open to a maximum of 3½ inches and rotate 90° at extreme extension. Payload capacity of arm is 8 oz. at maximum extension and 16 oz. at normal.

The remarkable HERO 1 robot is in production now, ready for you. Buy assembled or build it from a kit. Kit price is $1500 and the assembled robot is $2500, FOB Benton Harbor, or through your nearest Heathkit Electronic Center.

For full information on HERO 1 call 800-253-0570 toll-free. (In Alaska, Hawaii and Michigan, call 616-982-3411.) We'll give you the address of the nearest Heathkit Electronic Center and send you a booklet that gives details about the robot, the content of this course, and other information.

Please send details on the HERO 1 robot and robotics course.

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RO-100A

CIRCLE 10

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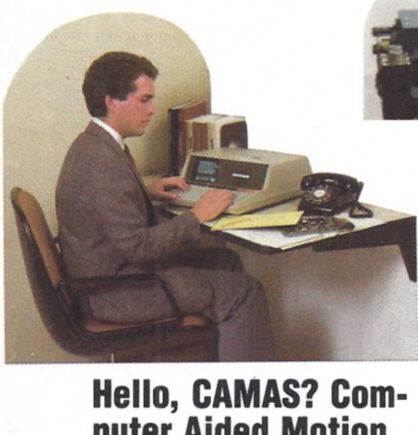
This is Ed, faced with some very tough motion control problems. A real stickler for details, he's exhausted from wrestling with inertia, torque and power requirements. But not for long. Ed's about to find that the best, most cost-effective way to match an entire motion control system is also the easiest.



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CAMAS also selects the SLO-SYN® Step Motors and Controls best suited for his task. And it even suggests the kinds of mechanical devices needed to accomplish the task—from simple gears and leadscrews to sprockets, chains or combinations.

In minutes, CAMAS provides a printout of all the variables and solutions Ed would have spent weeks on.

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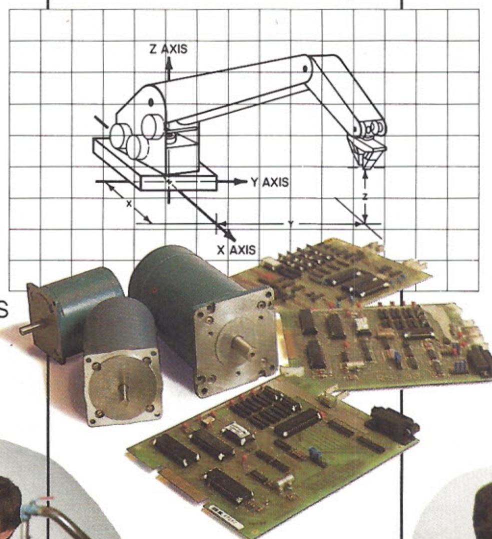
Ed wants to control his steppers from a desk top computer. But he's thinking ahead to the day he may want to utilize the company's larger CPU. With MODULYNX Motion Control's flexibility, Ed's covered all the way. New MODULYNX Motion Controls can easily interface through RS232C, IEEE488 or STANDARD BUS, 8-bit parallel ASCII, simple switches and TTL levels.

MODULYNX Motion Control is a series of individual plug-in circuit cards, each containing one step motor control function. Ed selects the exact cards he needs and plugs them in. He doesn't pay for more control than necessary.



MODULYNX Motion Control enhances performance.

With MODULYNX Motion Control, Ed can choose options for even greater control and accuracy. He can select:

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He can also select optional feedback capability for positional verification.

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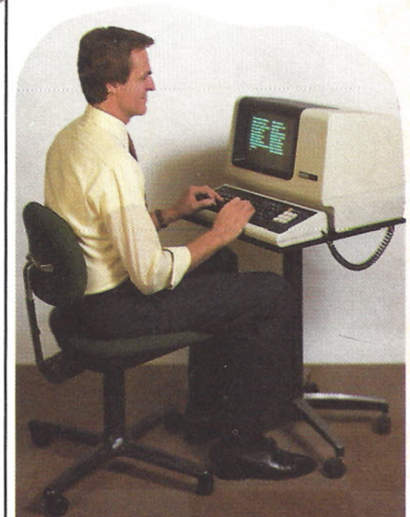
Take a lesson from Ed. If you've got a tough motion control problem, single or multiple axis, call Superior Electric. We can provide the superior solution. For complete technical information and the name of the Superior Electric specialist in your area, write us today. Or just call (203) 582-9561.



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CIRCLE 25

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Editorial

"Ein Heldenleben"

(Or, A Hero's Life, With Apologies to R. Strauss)

BY CARL HELMERS

This month's editorial is a photographic review and commentary on a new and exciting product, the Heathkit model ET-18 Hero-I robot. This product marks the start of a field that will attract numerous new entries in the coming years. With the beginnings of personal robotics in the form of autonomous and semi-autonomous mobile, real-time computer systems, Hero I marks a turning point comparable to the introduction of personal computers in kit form in 1975.

Hero is a complex machine which will provide endless hours of experimental inspiration. We had the good fortune to spend about a week with an assembled Hero-I last December, following the machine's press conference introduction. We start our inspection with a view of Hero in full dress, the only formal photo in the group. Following the photographs, we'll continue with general commentary on the meaning of a hero's life in today's Robotics Age.

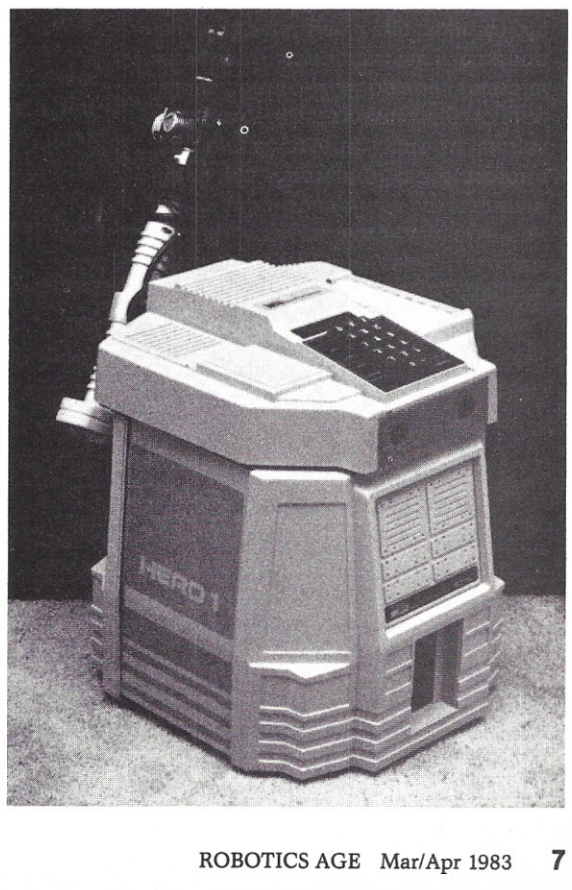

Photo 1. This is a finished Hero-I with (his?) clothes on. Heathkit's Hero-I robot is one of the first "real" personal robotics products. The end result is the mechanism which you see here—a mobile, self-powered, autonomous platform with an arm, limited sensor capability, and limited computational abilities. It intentionally exhibits some of the psychological implications of having a pet around the house, hence the personal robotics point of view for what would otherwise be an engineering training tool.

Editorial

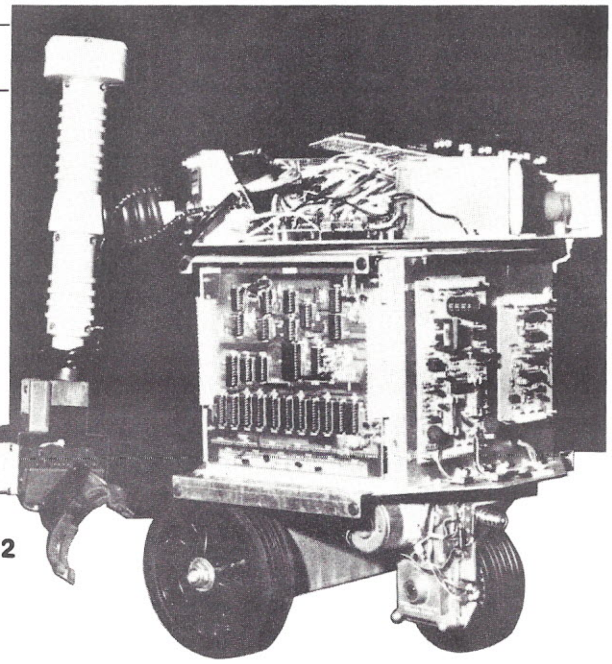
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Photo 2. A general view of a naked Hero. After taking off the cosmetic plastic shell, the chassis and arm of the Hero I look like this. Refer back to this photo as we examine some detailed parts of the design.

Central to the torso of Hero-I is a roughly cubical metal box. Three sides are rigidly fixed in place when assembled; the fourth side is a hinged door allowing access to the interior of the box. The two rear wheels are mounted under this central column, with three of the four gel cells mounted between them. The drive wheel is mounted at the front.

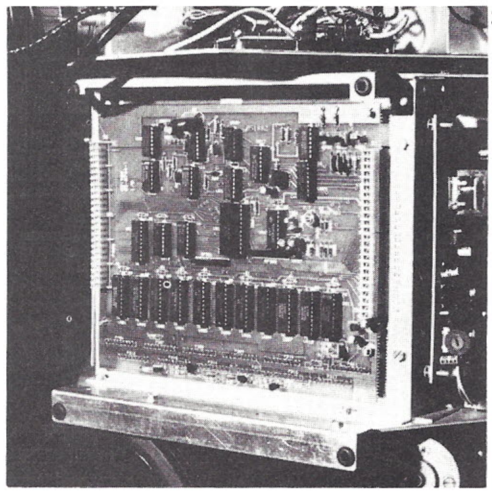
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Photo 3. Zooming in on the right side panel of the Hero-I, we see a detail of its mechanical assembly of electronic boards. The I/O board is clearly visible in this picture. Boards are generally mounted via plastic spacers on the exterior surfaces of the box for accessibility. Multiple pin plugs pass through the metal sides of the box to the interior for connection to the wiring harnesses.

The wiring harness "nervous system" of Hero is contained in the central box. Connectors on the wiring harnesses attach to the inner side of the pin plugs as well as to connectors on the externally mounted boards which are accessible through holes. The central processor board is mounted on the interior surface of the right side panel. It is connected to the same pins as the I/O board. As a result of the central boxlike mechanical structure, there is a large amount of room internal to the column potentially available for permanent augmentations of the robot's electronic control system.

4

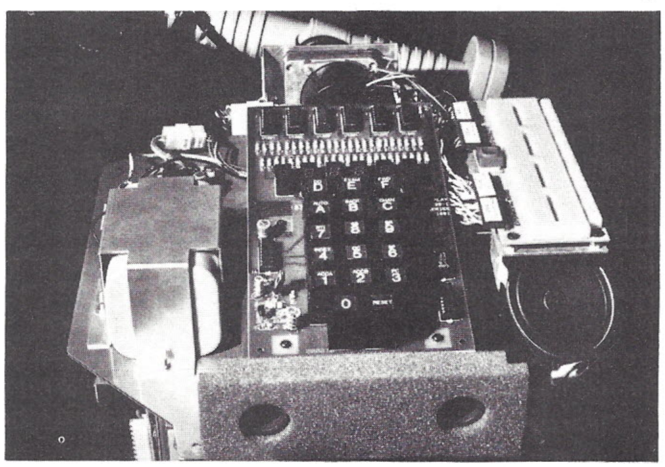


Photo 4: Turning our attention to the top of the naked turret head, we see a number of mechanisms and electronic features. The entire head assembly is built on a metal plate which rotates through an arc of nearly a full circle relative to the base. On the turret, we find mounted one battery, a keyboard and display, the experimental interfacing board, the manipulator arm, and all of Hero's sensors. We suspect that one of the key functions of the battery on the turret is to help balance the torques imposed upon the head bearing by the outboard weight of the manipulator arm.

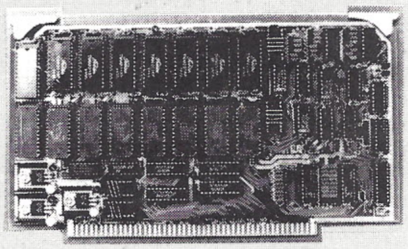
At the front of the head (bottom of this photograph), we see a rectangular solid made of plastic foam with two circular cutouts. The cutouts are at the end of collimation tubes for the sonar ranging device—one tube is the transmitter, and one tube is the receiver. The foam reduces unwanted direct coupling between the transmitter and receiver.

Continuing in a counterclockwise fashion around the turret, we see the speaker used as output for Hero's SC-02 Votrax chip voice. At the rear of the speaker is the experimental interfacing board (see photo 5). The manipulator arm is to the rear of the turret, at the upper edge of this photo.

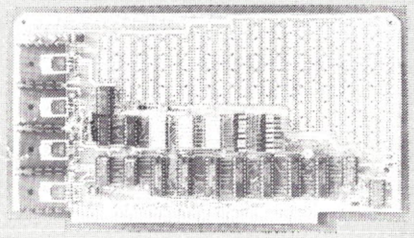
Not shown in this photo are three sensors which are mounted under the experimental interface board at the right edge of the turret: an ultrasonic motion detector, a light level sensor, and a dynamic microphone used for obtaining sound inputs.

S-100 UPDATE SHEET #4

the equation:



MEMORY



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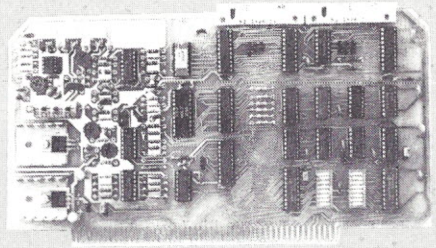
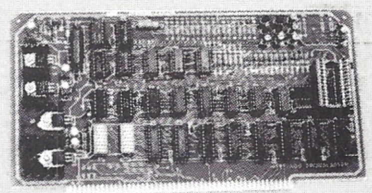


SPEECH SYNTHESIS



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CIRCLE 1

Editorial

Photo 5. The experimental interface board. Hero-I and its educational course are intended as a microprocessor hardware training product for individuals inside and outside an organizational context. A key part of this aspect of the system is this prototyping board, mounted on top of the turret.

According to Heath engineers, the internal bus of the on-board 6808 processor of Hero-I is brought out to the prototyping board. Microprocessor hardware portions of the Hero I course deal with building custom interfaces using this board and the on-board processor.

For experimenters such as yours truly and readers of this magazine, a key part of adaptating the Hero-I into integrated personal computer-controlled demonstration systems is the set of plugs along the edge of this board. By substituting a functionally identical interface to a custom designed radio or sound communication device, it should be possible to turn Hero into a true emulation of Shakey, the experimental robot of the early 1970s (see the book by Bertram Raphael entitled *The Thinking Machine: Mind Inside Matter*, published by W. H. Freeman in the mid 1970s). Shakey had an on-board PDP-11 of power comparable to that of Hero's 6808. Shakey's planning and strategy computations were performed by LISP programs running in a large PDP-10 computer with a radio link to the mobile robot. While not as powerful as a PDP-10, a typical contemporary personal computer can be used in the same fixed-base computer function.

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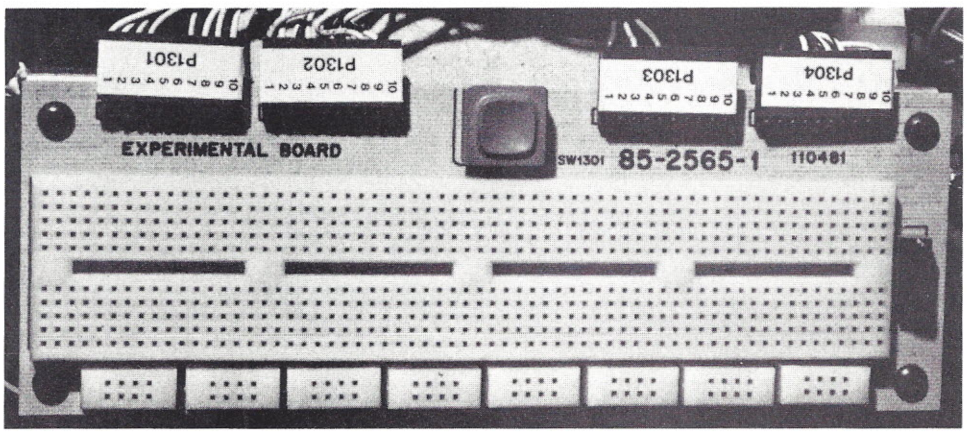


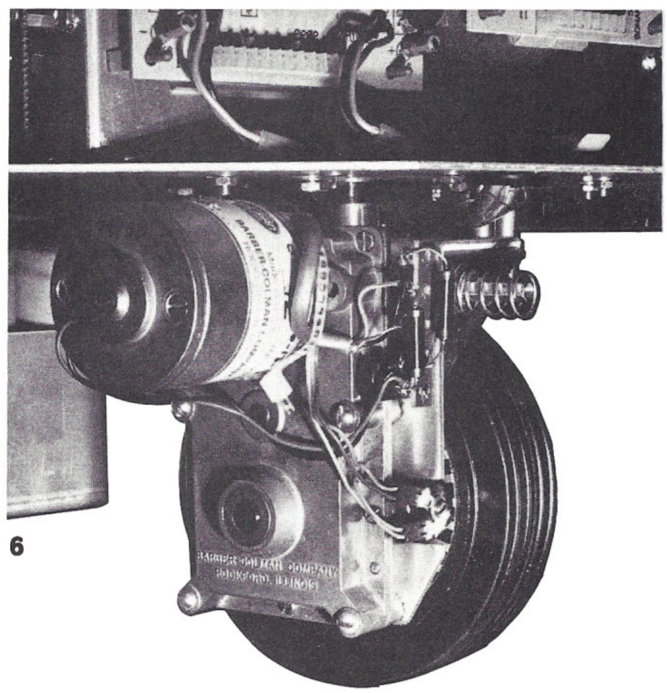
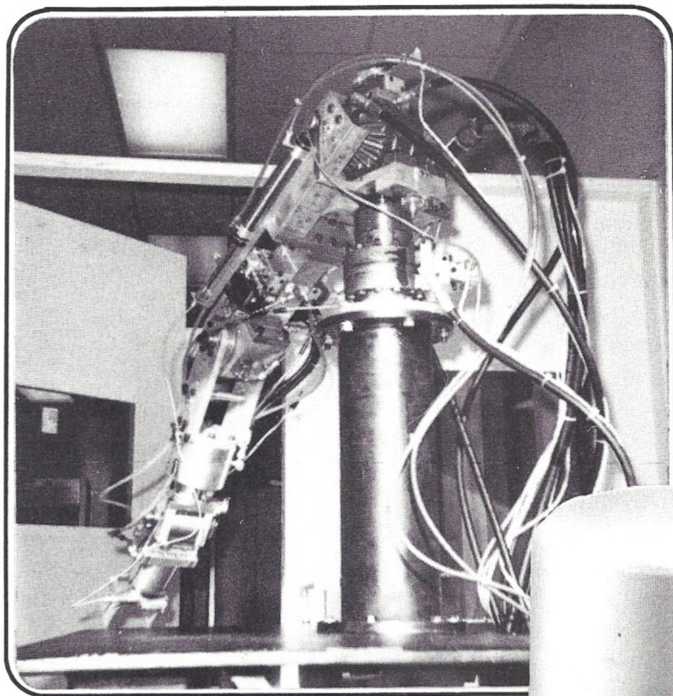


Photo 6. The Hero-I design is a three-wheeled platform. One wheel is a steerable drive wheel, shown here. The remaining two wheels are on a common axis fixed with respect to the base. (Refer to photo 2). The drive wheel is shown here pointing nearly straight forward. Several comments are worth noting.

First, the fundamental method of tracking the position of rotating shafts in Hero is the optical shaft encoder. As implemented with the drive wheel, there is a circular pattern of uniform width bars mounted on the rim of the wheel (see photo 7 as well as this photo). These bars either reflect light or absorb it—in particular, they reflect or absorb the light output of an LED as detected after reflection by a photosensor.

The drive motor is a fractional horsepower DC motor driving a reduction gear box, an assembly manufactured by Barber Kolman Company. The wheel is mounted directly to the output shaft of the Barber Kolman gear box. Also clearly visible in this photo and photo 7 is a pair of "choke" inductors used to suppress high-frequency noise caused by the motor commutators.

Given knowledge of the wheel position by the shaft encoding hardware, the Hero-I *attempts* to keep track of its physical location. It does this by tracking how far its drive wheel has rolled at a given steering angle. The only problem with this navigation method is that perfect wheels may never slip, but real wheels do. More on this later.



ROBOTIC ARM
1965

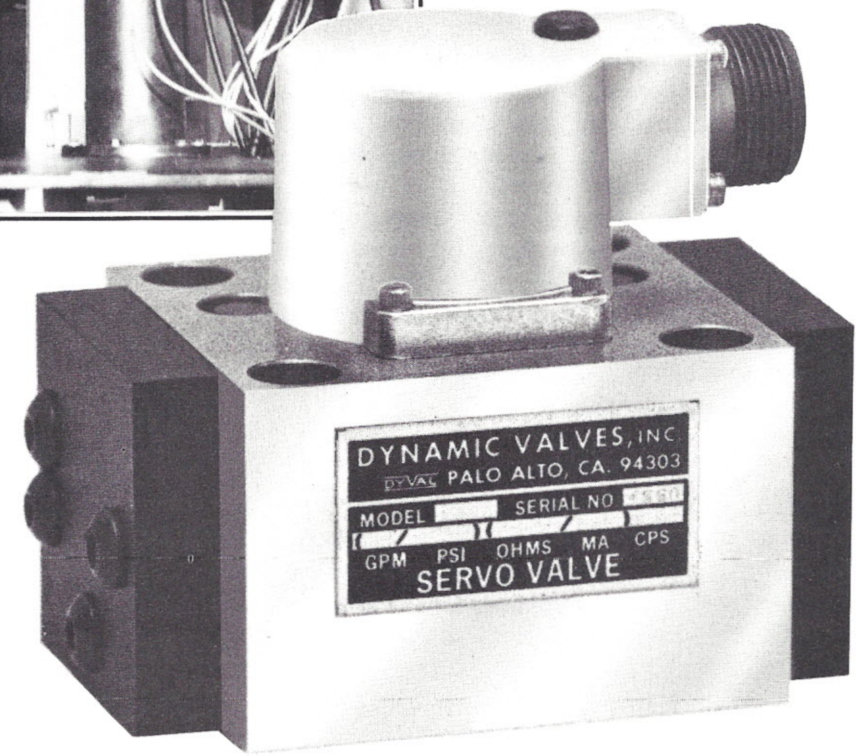


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Photo 7. Here we show the wheel rotated about 90 degrees from the straight forward position of photo 6. We show this rotation to point out the Hero-I technique for determining the end point of any given motor's motion: limit switches. The spring mounted on the steerable wheel's assembly is shown being deflected by one of two metal posts.

Look at the base of the post, where it joins the chassis. The post is insulated from the chassis by plastic washers. The contact of the spring with the post completes a circuit from the post to the chassis. Closure of the switch is used by the control microprocessor to stop shaft motion at the limit. A similar mechanism is used for the manipulator arm rotation and other joints in the system.

Other points of interest in this photo include the battery bank in back of the drive wheel, as well as another view of the optical shaft encoder of the drive wheel. Similar shaft encoders are used to track the steering position of the drive wheel, as well as the shaft positions of most rotating joints in the system.

Photo 8. Continuing the photographic review, a robot is incomplete without a manipulator arm and effector. Here we see the hand of a Hero. The claw can be opened or closed, using a ratcheting behavior when its limits have been reached in either direction. The amount of force available is intentionally limited to avoid the problem of damaging human beings and other biological inhabitants of this planet.

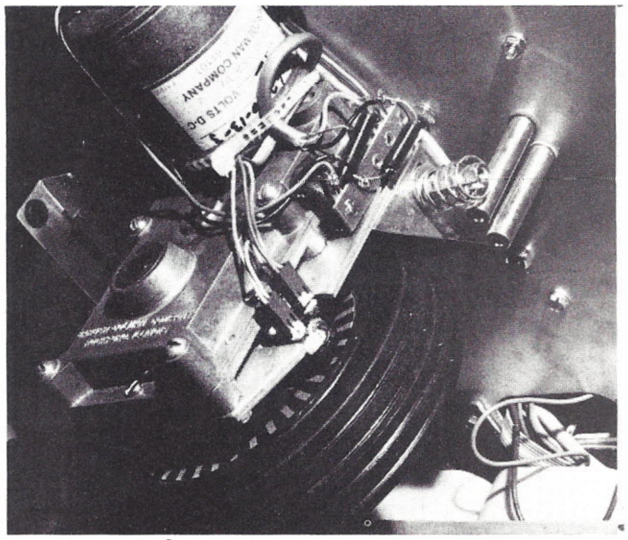
A sort of "wrist" action allows the whole claw to be rotated on two axes. One axis runs out through the center of the jaw. The second axis allows motion to and fro in a sort of waving action. The entire arm has a linear extension degree of freedom implemented with a lead screw arrangement.

Photo 9. Turning attention back to the top of Hero-I, this time with his "clothes" on, we can take a closer look at the programming console. Hero-I has an on-board 6808 microcomputer with 8K bytes of read-only memory systems programs and 4K bytes of user-available scratch memory.

Access to the microcomputer is through the pad shown. We'll give a couple of negative brownie points for the layout of the hexadecimal keypad as an array of 3 by 15 plus 2 keys instead of a more normal 4 by 4 array.

In our use of Hero for a week, we did not have access to more than an introductory technical document sufficient to verify that the machine worked. Given Heath's well deserved reputation for exhaustive and complete documentation, as well as a peek at a photocopy of the proofs at the press introduction on December 1, I can say

7



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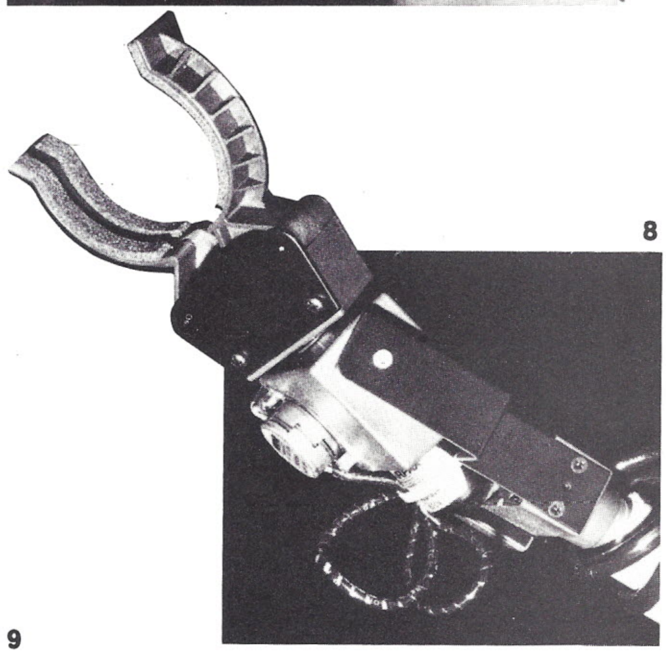

9

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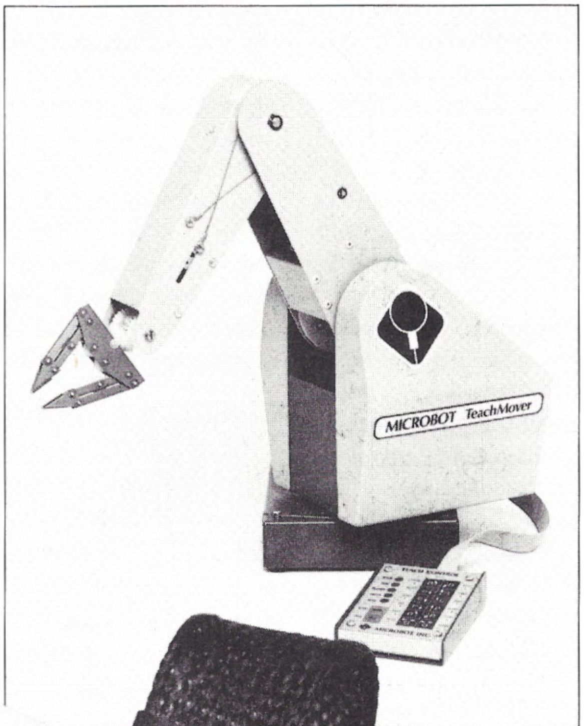

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RA

CIRCLE 16

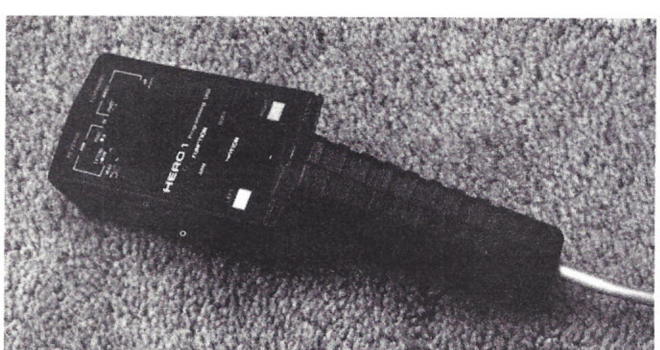
that a more complete manual will be provided with production units shipped by the time you read this.

Based on the preliminary information we had last December in the form of a user manual, the basic method of writing programs for Hero-I is a form of hexadecimal machine language augmented by a library of canned service routines for the machine's functions. The software tools incorporated in the read-only memory of the machine are primitive but useful. There is a single-board computer-style hexadecimal mode of interaction for entering a sequence of machine instructions. There is a "learn" mode for entering a sequence of instructions from the teaching paddle (see photo 10). There are built-in routines accessed by 6808 "jump to subroutine" instructions for specific addresses.

The outer level of the software in the standard ROM is a monitor which is entered upon power-up or upon pressing the RESET key. The monitor transfers to one of several execution states when one of the keypad's keys is pressed. The most important (and most painfully slow) mode is an initialization routine that exercises every motor through its entire range in order to calibrate the location of its shaft position encoders relative to mechanical stops. This routine takes several minutes to execute and must be performed fairly frequently to recover from random goofs in operations with the machine.

Other modes we used frequently during our trials included the "manual" control mode, the "learn" mode, and the "repeat" mode used to access previously stored programs.

Photo 10. We'll complete this photographic survey of Hero I with the key to its "learn" and "manual" modes of control, a handheld paddle that can control any of the motors in the machine. In the "manual" mode, this paddle simply selects which motor is to be operated, the direction in which the motor is to be run (forward or reverse), and whether or not the motor is turned on. The rotary switch at the top of the box selects which motor; the slide switch in the middle of the box selects one of two groups of motors: the head and arm motions, or the drive wheel and its steering angle. The combination of a trigger (under the paddle) with the direction switch (closest to the handle) completes the set of controls.



In the "manual" mode, all the paddle does is individually control motors. In the "learn" mode, the paddle simultaneously performs a manually directed operation and records the operation in memory for a later repetition. Since the method of encoding programs is simply a series of subroutine calls to standard library routines along with the detailed parameters, all hexadecimal texts seem to be inherently relocatable, allowing manual editing. The "learn" mode also provides for backing up over mistakes and recording new patterns in their place. Once a program is in place, it can be saved on a cassette tape, the only form of user program mass storage available with the machine.

Summary and Critique. Hero I is beautiful. It is a product which provides a basis for experimentation and learning about the problems of real-time systems under the control of microcomputers. It is the kind of personal robot appropriate for today's marketplace—a machine intended for exploration and learning about the problems of controlling real-world systems with the computers of intelligent machines.

Hero is a product of that functional tradeoff which has to be made at any given time in the evolution of technology. What can we learn about the present state of technology and future areas of improvement given Hero's present example?

We expect that Hero will become a standard test bed, a starting point, for many interesting experiments in design of mobile, autonomous systems. Until we see additional entries in the marketplace, Hero, with its intended emphasis on experimentation with sensors, computers, and electronics, is where the action is. Each of these comments could individually expand into a project with a life of its own as readers explore the ideas of personal robotics. The comments which follow are intended as inspiration for experiments with Hero. Some of these will ultimately appear in coming issues as technical articles on a Hero theme.

The major enhancement we see needed for the Hero-I as originally introduced is attention to one crucial design issue. This is the issue of expanding Hero's effective on-board computer power. Hero's on-board computing facility is understandably primitive. Given the complicated matter of trading price and performance off against the expected

marketplace for a product, one cannot quarrel with the choice of elements of Hero's design. But, being technologically greedy for performance, wouldn't it be nice if we had more computer power?

Hero's memory is limited. It is not significantly greater than the memory one could find on a single-board, engineering-oriented computer. We could adjust this factor with a few dollars thrown in a couple of technological directions. One is to put more computing power and peripherals on board (at the price of weight and power consumption penalties.) A second is to take the Shakey option—a communications link by radio, sound, or cables to a fixed computer with considerably greater power. Intermediate between these two extremes is the procedure used by Charles Balmer in Avatar (see *Robotics Age,* Volume 4, number 1, January/February 1982). Avatar carries its complete computer system with it, but only connects to floppy disks, printers, and terminals when in a stationary program development mode. Greater effective on-board computing allows use of better software development tools.

As Hero enters production, there is only a very limited form of software development support: an audio tape interface to store program patterns which are manipulated in memory using the hexadecimal-oriented tools built into its standard read-only memories.

The first level of augmentation possible is available for the price of a personal computer, an audio interconnection cable, and the time spent integrating some software tools. The key is the cassette tape interface and a non-real-time batch transfer mode of communications. Speaking from our own experiences with small computer audio cassette interfaces, it is quite possible to use the audio cassette port channels of a larger computer, such as a bigger Heath system, an Apple II, or Radio Shack machine, to drive inputs to the audio cassette ports of a computer with much more limited peripherals. We've shown this to be a practical software development technique presently in use as a part of our development work for consumer computers.

Given an engineering specification of the tape format, a few further days with the Hero-I, and an appropriate personal computer, then the first communication augmentation of Hero can happen: the ability to conceptually develop and simulate programs on a personal computer which are then batch-loaded to the Hero-I on-board computer by this simple audio patch to the cassette port. The patch can work both ways, for the personal computer system can read the audio signal dumped by Hero-I to its cassette port as well. Hero will think he's talking to a cassette recorder.

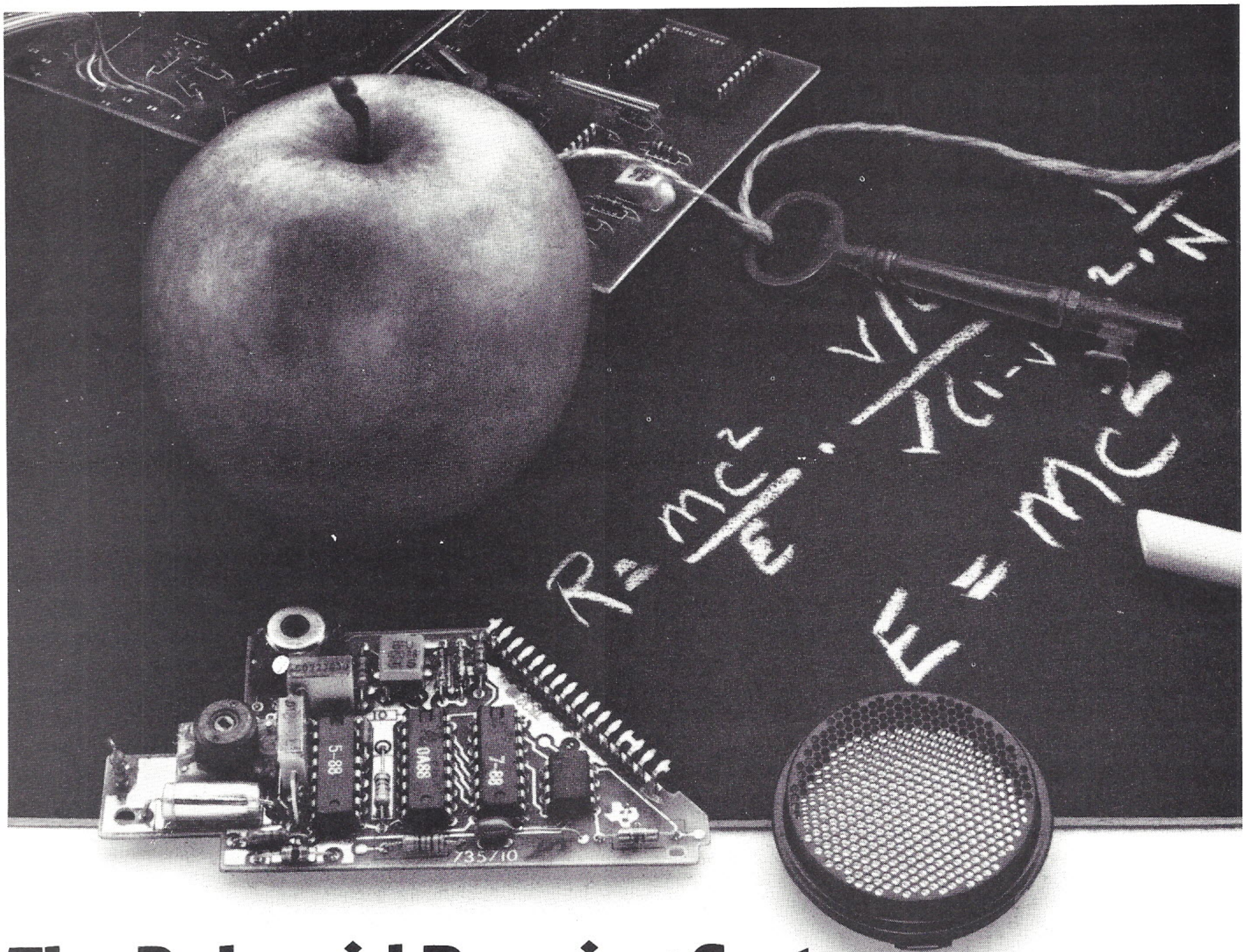
A more elaborate improvement to the basic Hero-I implementation is to extend communication into real time. The concept here is to replace the experimental interface board at the top of Hero with a custom peripheral for communications purposes and modify the standard ROM operating system with extensions to use the new port. We can then proceed to write programs which run in the big computer, responding to Hero's general control needs as required. In this conception, Hero's present on-board computer becomes a low-level controller, carrying out orders from the software development computer and reporting back environmental conditions it perceives. The fact that we would communicate by means of radio or high-frequency sound waves does not greatly affect the problem; it is a proven technology for autonomous robots. This is the strategy used, for example, in robot space exploration machines such as Viking, Pioneer, and Voyager.

One of the critical design problems of every autonomous mobile robot is power. Mechanical motion uses much power. A machine with no mechanical components, such as an electronic wristwatch, can run for years on an extremely small battery. But as soon as your wristwatch has to have powered wheels and a manipulator arm, that tiny battery would be drained in milliseconds if not microseconds.

This power-versus-weight problem is the same one faced by all vehicle designers. The engineering tradeoff of using liquid petroleum products in automobiles might have some attraction for future robotic systems in certain contexts. The energy density of gasoline or diesel fuel is quite high compared to batteries.

A robot like Hero is essentially a small, battery-powered vehicle, with all the energy density problems of heavy batteries and limited watt-hours. Hero's power system includes a recharging unit with umbilical cable, but requires human intervention for actively setting up a recharge operation. Internal to the standard operating software and hardware is provision for budgeting the power Hero uses. The internal real-time clock of Hero's computer can be set up

Continued on page 44



CIRCLE 28

NUCLEAR POWER PLANT EMERGENCY DAMAGE CONTROL ROBOT

James Gupton
7416-G Pebblestone Drive
Charlotte, North Carolina 28212

Early in 1979, an accident at the Three Mile Island nuclear power plant focused attention on the potential radiation hazards associated with the generation of power by nuclear reactors. This drew national attention to the future potential failures of reactor hardware, cooling piping, or control devices and the resulting release of radioactive liquids or gases into the reactor building. The reactor building is designed to contain radioactive spills, barring structural damage to the building. Such contained spills would result in radiation levels too high to permit the entrance of humans. The only effective method of shutting off the source of the spill and making emergency repairs would be the use of robots.

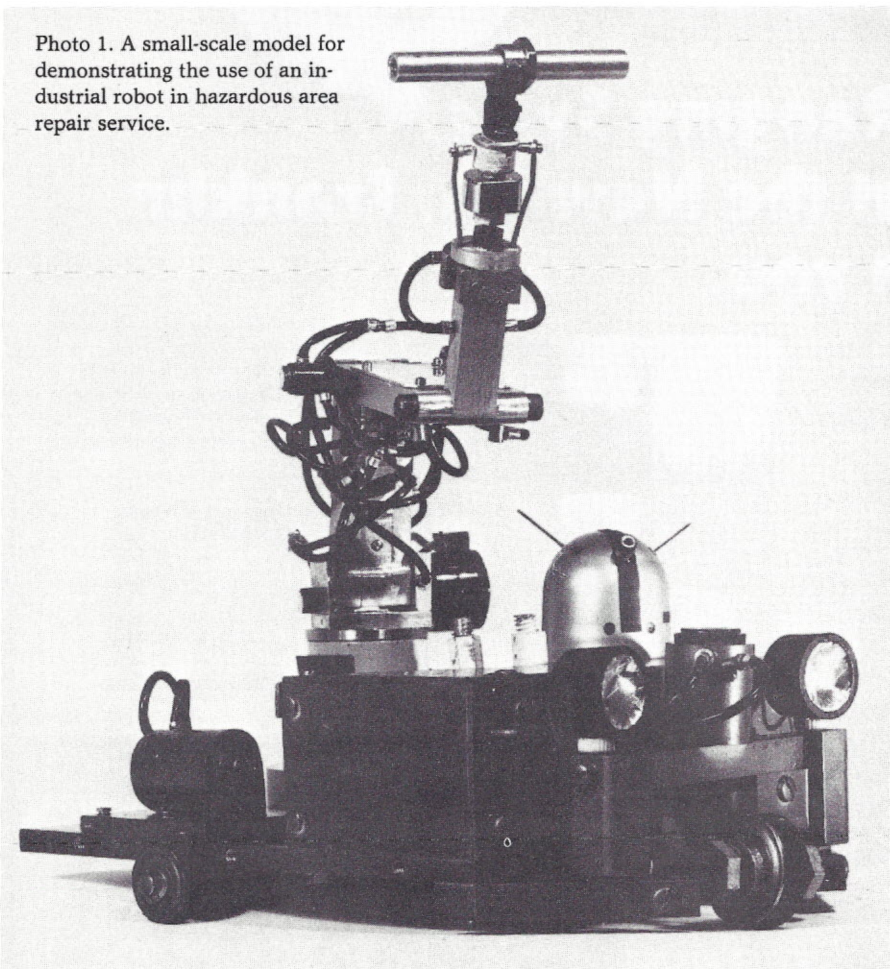


Photo 1. A small-scale model for demonstrating the use of an industrial robot in hazardous area repair service.

If the technology exists to develop nuclear power generation, so should the foresight to apply the existing technology of industrial robots as a safety factor. Industrial robots have been in use for the past 20 years. They work tirelessly, performing welding operations, material handling, material fabrication, and control of parts moving along conveyer belts.

The current limitation of applying industrial robots to nuclear power plants lies in their design of a fixed base, which permits no movement from the fixed location. Most robots have only body rotation and movement of the work arm through the xy coordinates, rotation of the wrist, a gripping action of the manipulators and special-purpose work tools for welding or cutting.

Robots used for emergency repair at a nuclear power plant must have capabilities similar to present industrial robots. They also must be able to do the following:

- See the extent of damage and relay this data to the damage control operator.
- Have mobility in an explosive hydrogen atmosphere or under radioactive water.
- Interchange the work hand.

The mobile robot base requires heavy steel construction in order to support the weight of the two robots, its on-board motor power source, and the weight of tools and repair materials. All motors, lights, electronic equipment, and interconnec-

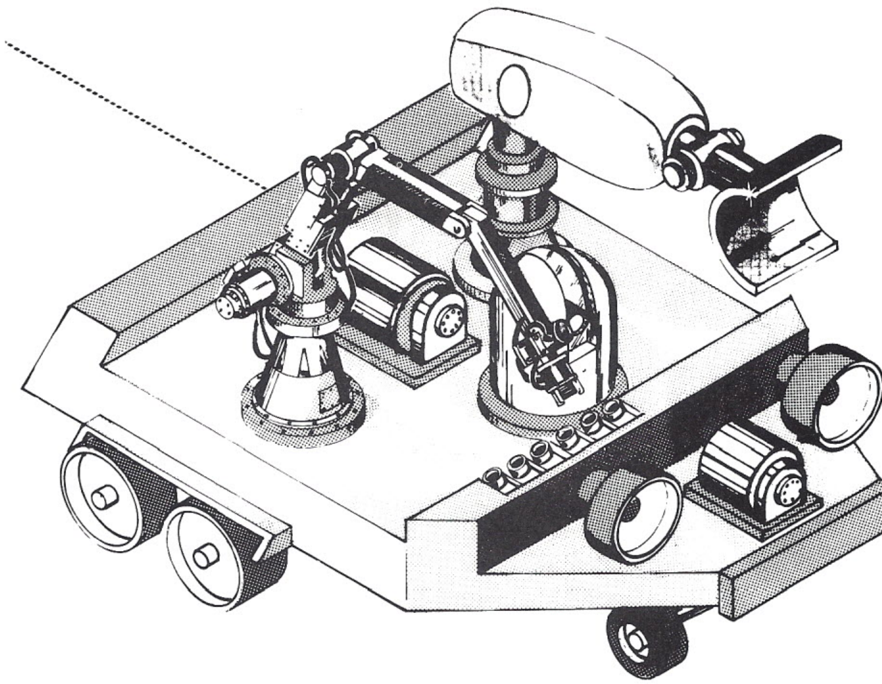


Figure 1. Artist's conception of a dual-armed, industrial robot on a mobile base for nuclear power plant emergency damage repair.

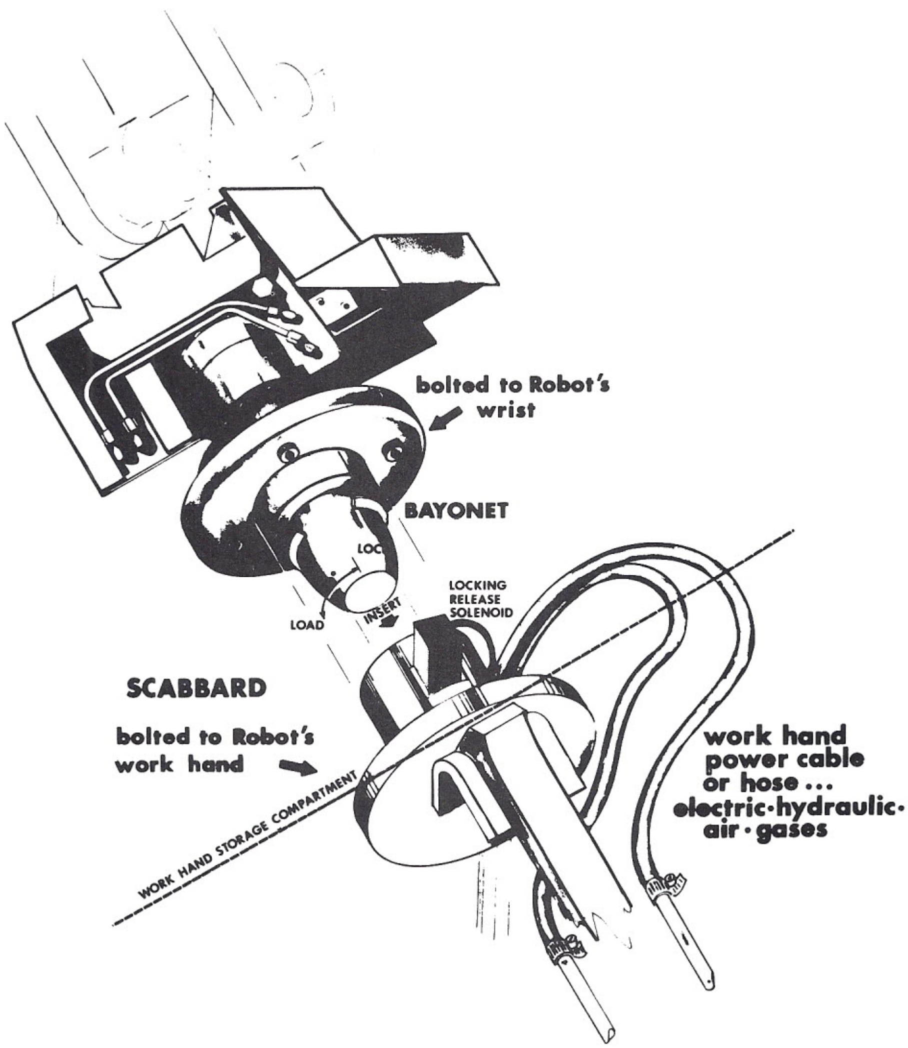


Figure 2. A possible design for an automatically interchangeable work tool.

tions must be both explosion-proof and waterproof.

Communication between the damage control operator and the robot could be done by modulated beams of light transmitted by an umbilical cord of optical fibers or a modulated HeNe continuous-wave laser. This communication method eliminates any possibility of RF power creating a spark and igniting explosive hydrogen.

Figure 1 is an artist's conception of a two-manipulator damage control robot. Drive and steering motors are in sealed housings, a rotating television turret is centered between the two manipulators, and lights are adjustable through both the x and y axes. An industrial robot manipulator, such as the Cincinnati Milacron, is positioned on the right-hand side of the robot base. It is modified to allow automatic interchange of work hands. The robot on the left resembles Unimation's industrial robot. Its purpose is to lift and position repair materials for welding. Its telescoping arm is ideal for this application.

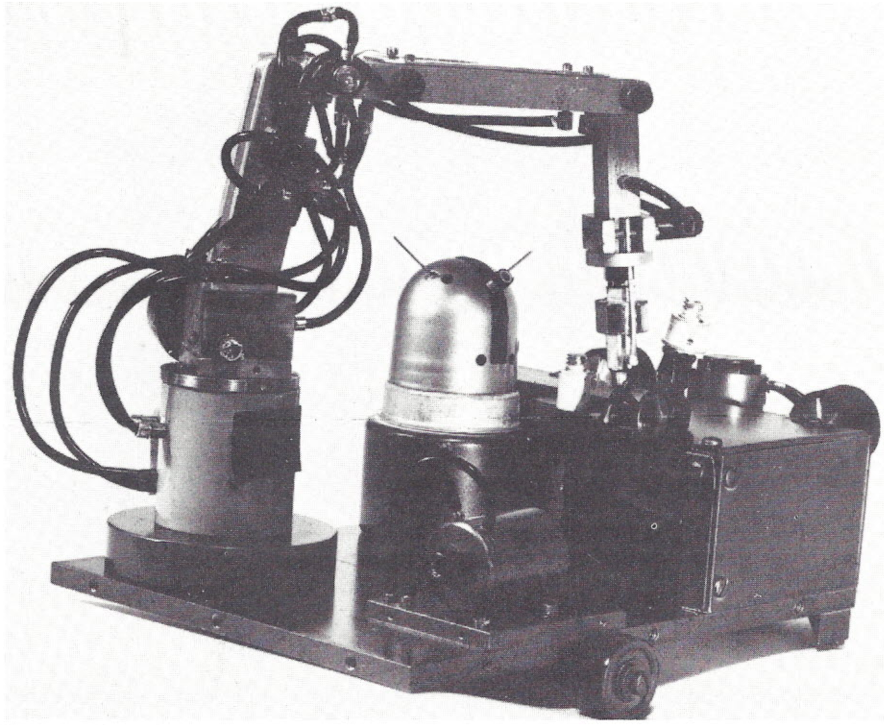


Photo 2. The industrial robot arm selects the next work hand needed from a storage compartment over the mobile base battery compartment.

A scale-model mock-up was constructed to demonstrate how a damage repair robot would perform. Photo 1 shows this model, with a single industrial robot in the act of raising a section of cooling water pipe. For this type of work, the robot uses a heavy-duty, clamp-like tool. Below and to the right of the upraised arm is the robot vision turret. In the ideal situation, the mobile base lights would rotate and elevate in synchronization with the television camera and turret. The television camera would move from 0 to 90 degrees vertically and make a complete 360-degree circular rotation on its base.

Photo 2 shows how the robot manipulator could store its heavy-duty clamp work hand and attach another work hand to perform cutting, riveting or welding action, as the repair task requires. The work hand in service is placed in a storage compartment, as shown in photo 2. The work arm's wrist then rotates counterclockwise to release the work hand.

Figure 2 is a drawing which shows how the "bayonet" wrist would be inserted into the "scabbard" type of receiver on the work tool hand. If the

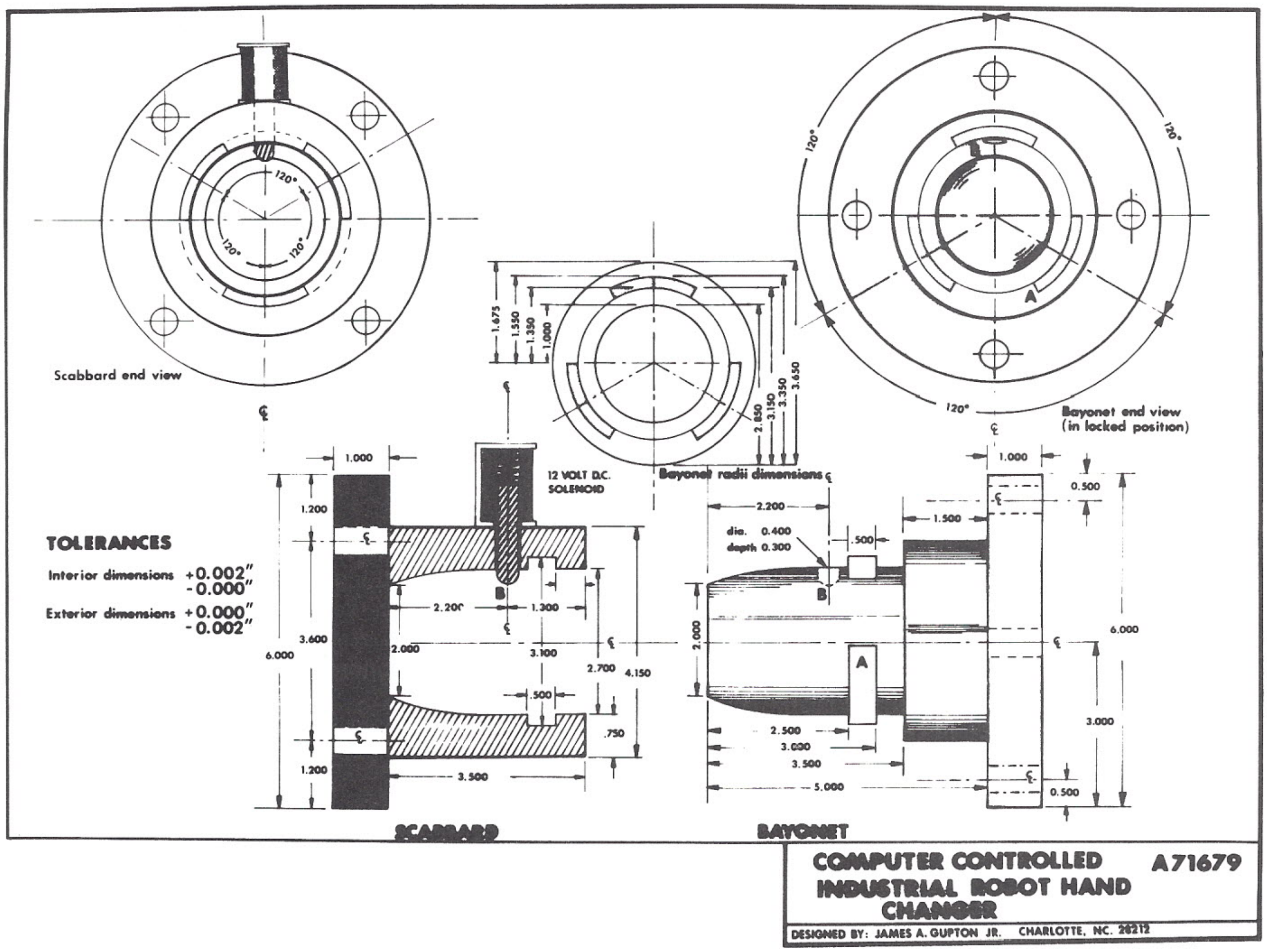


Figure 3. Detailed drawings of the computer-controlled, industrial robot hand changing sections. Details of the scabbard and bayonet are shown.

work tool hand requires electrical, hydraulic, etc. power, it is already attached to the sealed motor while the work hand is in its storage compartment. A supply reel then permits the work hand motor to operate anywhere within the radius and arm movement range of the working robot. Figure 3 is a detailed drawing of the hand changer.

Assuming the damage control robot is designed around the Cincinnati Milacron and the Unimation Model 4000B industrial robots, the mobile base would need to support the 7700-pound working weight of the Milacron and allow 36 square feet of mounting space. The Unimation Model 4000B would add another 4300-pound weight load and requires a 29.3 square foot base area. The total power requirement for the two robots is 56 KVA.

This power draw would require power site connections at strategic locations within the containment building. The robot could then extend a power arm from its base, on practically the same principle as airborne aircraft refueling, and be completely free of power umbilical cables for complete mobility.

The mobile base lights, control, television camera, and drive motors would be powered by a silver/nickel battery assembly which is automatically charged any time the 56 KVA power connection is connected to a site power source. The weight of such a silver/nickel battery would range between 2000 and 3500 pounds, which brings the total support requirements of the mobile base to approximately 16,000 pounds, exclusive of its construction material weight. A gross weight of 20 tons seems realistic for the operational weight.

The initial concept of the damage repair robot was for nuclear power plant emergency use. There are other applications which might have even greater value for such a robot:

- Fire fighting in building structures, oil rigs, gasoline storage areas, shipboard fires, and so on.
- Natural disasters, such as floods, hurricanes, undersea rescue, mine disasters.

The robot would already be waterproof and explosion-proof. We need only to make it fireproof to apply its functions to these other disaster areas. □

Author's Note: The robot and the hand changing capability is covered under invention disclosure number 087122 dated 7 January 1980.

Calendar

Continued from page 3

Institute, the conference will provide a forum for new research and study results in the technical and social sciences. Session categories include international and legal considerations, nonterrestrial materials resources and processing, electromagnetic accelerators, space stations and habitats, biomedical and social sciences, the economics of space in private enterprise, and new technical concepts. Dr. Gerard K. O'Neill, Professor of Physics at Princeton University and president of the Space Studies Institute, is chairman of the Conference Organizing Committee.

JUNE

June 14-16, 1982. International Robot Conference and Exhibition (INTEROBOT). Long Beach Convention Center, Long Beach, California. Contact: TCM, 143 North Hale Street, Wheaton, Illinois 60187. Phone: (312) 668-8100.

Sponsored by *The Robotics Industry Directory*, INTEROBOT is expected to attract a highly-qualified audience of production, research, design, and management people. Products on display include robots, positioning tables, programmable controllers, vision systems, CAM systems, computer hardware and software, and a wide range of components.

June 7-11, 1983. 1983 Rochester Forth Applications Conference. University of Rochester, Rochester, NY 14623. The third annual Rochester Forth Conference will emphasize the use of Forth in robot applications. Topics include: mechanical and electrical engineering, vision, artificial intelligence, computer networking, and automated manufacturing.

Papers are requested in all conference topics. The papers will be presented in either oral or poster sessions. A 200 word abstract must be received by April 15, 1983. Final papers must be submitted by May 15 for the oral session and June 1 for the poster sessions. Papers are limited to a maximum of 10 printed pages.

JULY

July 25-29, 1983. Robot Manipulators, Computer Vision and Automated Assembly. Artificial Intelligence Laboratory, Massachusetts Institute of Technology, Cambridge, MA 02139. Contact: Director of the Summer Session, Room E19-356, MIT, Cambridge, MA 02139.

This is a summer session course which is designed to prepare the participant for the sophisticated methods soon to be employed in advanced automation. The emphasis is on developing strategies for the solution of problems in sensing, spatial reasoning, and manipulation. The use of existing industrial robots and binary vision systems is covered as well.

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ARTIFICIAL INTELLIGENCE AND THE NATURE OF ROBOTICS

Alfred B. Bortz
1312 Foxboro Drive
Monroeville, Pennsylvania 15146

The quoted passages are from statements made by Professor Herbert Simon during interviews at Carnegie-Mellon University on June 25, 1980 and September 29, 1982. This article is an excerpt from the book, *Robotics: A Decision Maker's Guide,* which is scheduled to be published under the CBI imprint of Van Nostrand Reinhold.

His Ph.D. degree is in political science. He holds the prestigious title of University Professor of Psychology and Computer Science at Carnegie-Mellon University (CMU) in Pittsburgh. He is a Nobel Laureate in Economics. And he is one of the founders of the modern discipline of artificial intelligence, also known as AI.

You would assume that, with these varied credits to his name, the range of Herbert Simon's research interests would be wide. But that isn't so, said Simon in a recent interview. "My lifelong research interest has been in decision-making. I haven't moved an inch from that for 45 years now."

An interview with Herbert Simon is an experience to savor. You first find Baker Hall, one of CMU's original buildings. The first and second floor hallways slant downwards from the front of the building to the back. It is said that Andrew Carnegie wanted them built that way when he endowed the school; if it failed as an institution of higher learning, the building could house a factory assembly line. The third floor is discontinuous, so each stairway has a sign telling the numbers of the rooms to which it leads. One stairway has a sign with a large Greek letter Psi and the words "Psychology Department, third floor." At the top of the stairs is an unpretentious steel door with a small plastic label which reads "H. A. Simon."

This article summarizes two interviews with Carnegie-Mellon University Professor Herbert A. Simon. The interviews covered topics which include the comparison of artificial and human intelligence, robot sensors and grippers, and Simon's Nobel prize winning work on economic theories which "take account of information-processing limitations on the decision-makers."

Simon, shown here, identified planning as "the biggest contribution AI can make right now" in robotics. Looking to the future, Simon saw other applications of artificial intelligence in robotics, including such down-to-earth applications as automatic bulldozers and expert systems which successfully steer a supertanker into a harbor.

Behind that door are two offices, Simon's and his secretary's. Simon's is spacious, cluttered, professorial. When you recall that ordinary professors don't have secretaries, you are reminded that Herbert Simon is no ordinary professor. File cabinets bulge with his published papers, course notes, lecture notes. Somewhere in there is a copy of an address he delivered to a prestigious gathering of scientists in Stockholm in 1978.

Simon extends his hand to greet you. "Good to see you!" he says and means it. You settle into a chair and begin your interview; it's more like a conversation with an interested friend. Only when you return home to transcribe the tape do you realize the nuggets of wisdom and humor that Simon has given you.

Artificial Intelligence. CMU is one of three universities regarded as the centers of excellence in AI research in the United States. (MIT and Stanford are the others.) Unlike many universities, CMU has emphasized entrepreneurial spirit as well as scholarly activities. It was natural for CMU to take a bold step in 1980 and build a robotics institute around the scholarship of Simon and his colleagues, people like Professor Allen Newell, who has worked with Simon since the 1950s, and Professor D. Raj Reddy, an expert in speech synthesis and recognition, who was appointed director of the new institute.

Shortly before the Robotics In-

stitute opened, Simon explained the connection between AI and robotics: "The whole reason why we're starting up a robot project at Carnegie-Mellon is because we have a very large group of people who are at the frontiers of artificial intelligence, and some of us are interested in seeing what kinds of real-life applications there are. What part of this existing and developable technology of artificial intelligence have we wits enough to find application for in these industrial settings? The kinds of applications that the group will select to focus on will be problems where we think that the current kinds of robotry will not do the job or we think intelligence really is called for."

In their university setting, the scientists and engineers of the robotics institute are more interested in developing and designing the next generation of robots than in applying existing robots. That new generation will be characterized by applications of AI, as Simon explains.

"If we're talking about applications at present, artificial intelligence plays a very modest role. Present robotics is largely based on control theory concepts that have come out of engineering. Insofar as the systems give signs of intelligence, it's because feedback controls have been arranged. But the underlying technology that these feedback controls are based on is not the technology that we would call artificial intelligence. It's much more classical engineering technology.

"That has its limits. There are various kinds of strong restrictions you put on it because you've been guided by the mathematics and what can be done with the mathematics. The promise of AI is that you'll have a number of ways of producing responses to the environment, responses to stimuli, that are more flexible than the kinds of responses you can get with this classical control technology. Responses to different kinds of stimuli, according to classical control theory, depend on everything being numericized or arithmetized; whereas with artificial intelligence techniques, you can use natural language input and other kinds of symbolic inputs that are not numbers.

"You can think of the kinds of industrial robots that are being planned and installed now as a natural continuation of the kinds of mechanization and automation that have gone on for 100 years. To take the next step, to go any farther than we've gone today, there's got to be a lot more between the ears of the robot. There's got to be some intelligence."

Exactly what does artificial intelligence mean?

"Artificial intelligence," says Simon, "is the exhibition of behavior by computers which would be called intelligent if it were exhibited by human beings."

But human beings exhibit a wide range of behaviors and traits. How far is Simon willing to carry the analogy? Far enough to lead us down an interesting detour before we return to the topic of robotics.

AI and Human Intelligence. When asked, "In what sense is artificial intelligence like human intelligence?" Simon replies, "I occupy one of the extreme wings on this. The way we tell if a human being is intelligent is we give him certain tasks and see what he does with them. Intelligence has to do with the ability to respond appropriately to complex situations. Every time we write a computer program to do that, particularly if it's a fairly general program, I find it quite natural to speak of the computer as exhibiting intelligence."

Artificial intelligence programs have been written which make it possible for a computer to learn. Humans, however, do more. They learn how to learn. They organize facts, generalize, build hypotheses, and test them. In that sense, humans are self-programming.

Simon believes that computers can do all that, too. Describing a computer program written by his student Patrick Langley, he says, "BACON is a program which likes to look at bodies of data and find invariants in them. We gave it, for example, some data on the distances of the planets from the sun and their periodicities,

and BACON, with very little search, discovered Kepler's Third Law."

He admits that "of course, we gave it problems that we thought it could solve, but the interesting question is what did it use to solve them. What it used were a few heuristics that were not subject matter dependent. A lot of scientific discovery is data-driven, and the heuristics used to find things in those data are very general."

Simon laughs when he recounts the way BACON discovered atomic weights and atomic numbers from chemical data. "This is essentially the path that Dalton, Avogadro, and Cannizaro followed from 1800 to 1860. The wonder is why they took 60 years. We have some hypotheses about that, too. People are going to make your response (that the researchers gave their program problems which they knew it could solve) until the day when we get BACON to discover a new law."

BACON uses built-in heuristics to discover order in data, but it would have to get up early in the morning to outdo AM, a program that develops its own heuristics. "Doug Lenat (at Stanford) has a program he calls AM, I think for artificial mathematician," Simon explains. "It has three things. You give it some basic knowledge about something. The most interesting thing it did was with some basic knowledge about set theory . . . the first two weeks of a course in set theory.

"The second thing he gave it were some heuristics about what made a concept interesting: a concept is interesting if it is related to a lot of other interesting concepts. A concept is interesting if you can find examples of it, but they're not too easy to find. It is interesting if it has strong consequences, etc. Whole bunch of 'em—50.

"The third thing he gave it were some hints about how you go about looking for interesting concepts. If you have a concept, find examples of it. Look at extreme examples and try to build a new concept around them . . . about 100 of these.

"In about two hours of PDP-10 (a major mainframe computer) time, the program discovered the natural numbers, thought they were a little interesting, discovered the operations of addition, subtraction, multiplication, and division. . . . It found that numbers have divisors and got interested in the extreme case of numbers that had only two divisors (prime numbers). It found out some properties about them. It conjectured that any number could be represented as the product of powers of primes. . . ."

After Simon finished ticking off the conjectures of AM, he went to programs that teach themselves. "Now if you want a program that can program itself, we're doing some work on learning around here, and one of the current doctoral theses by David Neves is a program that learns from textbook examples. . . .

"What Neves' program can do is to examine that step-by-step example (solving a linear equation) and on the

basis of that, program itself to solve linear algebraic equations, not just the equation it saw the example of.... The particular case it worked on is something a typical high school algebra course would spend a week on."

Another program learned how to solve basic physics problems in the area of kinematics, the description of motion. Simon thinks that program could do more. "It's not clear whether you need more sophisticated programs when you move from that to quantum mechanics or whether you just need to have all the previous weeks. My own hunch is that it's the latter."

Human intelligence has other dimensions besides learning. Humans are creative, insightful, and have senses of humor and emotion. Simon insists that artificial intelligence can have the same dimensions.

Concerning creativity, he cites examples from music, art, and game-playing. In 1956, a program on the ILLIAC computer wrote "The Computer Cantata." Simon says, "I have sat professional musicians down to listen to it and asked them for a judgment as to whether it is musically interesting.... The answer is yes, they find it musically interesting," even if they are not aware of its source.

Simon and others also regard computer-generated art as interesting. Duane M. Palyka's work has been exhibited in the Museum of Modern Art in New York, and Simon has a piece of Palyka's work hanging in his living room.

Game-playing requires a different kind of creativity. Simon cites CMU Professor Hans Berliner's backgammon program, which defeated the world champion in a match in Monte Carlo in 1980 and several chess programs which have attained expert ranking. Humans can still take heart from the results of a human-versus-computer chess tournament held in conjunction with the 1982 AAAI (American Association of Artificial Intelligence) Conference in Pittsburgh. When the humans are computer scientists, they can exploit weaknesses in the programs.

Michael Goodside, for example, played a simple strategy in which he planned for the coup-de-grace to come approximately 30 moves ahead. The program, which was excellent in playing brute-force, look-ahead chess for about 6 moves, fell into Goodside's trap. The commentator describing the game to spectators outside the room quickly perceived the plan and began predicting both players' moves with nearly perfect accuracy.

Simon believes chess programs have more than brute force capabilities; they also have insight. "Insight is a label we apply when somebody is presented with a situation, and with some kind of suddenness, he responds to it intelligently. We know a good deal about that in human beings. A person who is very experienced in a particular field looks at a situation, sees in it a pattern which tells him what to do because that's what you always do when you see that pattern.

"What's surprising about it to us when it happens to us is that we don't know how we did it! The process involved, as near as we can tell, is exactly like the process when you recognize an old friend. You look at his face, you sort the features down your discrimination net, and you say, 'Oh, that's Joe!'"

No one has written a program with a sense of humor, but Simon knows where he would start to write one. "What's involved is knowledge of what's expected and a disappointment of those expectations." The knowledge of what is expected is the difficult part. There's a lot of context involved in understanding a joke. "That's why Englishmen don't understand American jokes and Americans don't understand English jokes," Simon comments.

Simon answers the question of computers and emotions by looking at the basis of human emotions. People have attention, which enables them to focus on important parts of their environment and interrupt mechanisms, which enable them to respond to changes. "By the time we have all those things in the program," he says, "we're beginning to get a system which is rather analogous to human emotion.

"You might ask, 'But is it really emotion?' There is a philosophic position known as solipsism which says, 'I know I have emotions, but the only reason I credit you with emotions is that it's a convenient theory since you look so much like me.' I could apply that language to my computer. At that point, it becomes a rather difficult philosophical question as to whether you want to attribute emotions to it.

"Probably the line will get very hard to draw at the time we have computer programs that have images of themselves as part of their models of the world. Then you're going to have to ask whether they have consciousness or not."

Using Sensory Information. Despite the nearly unbounded future which Simon sees for AI, he is realistic in terms of what its immediate benefits are in robotics. He points out that "an important current bottleneck in how far we can apply robotics is on the side of sensory devices. What kind of information can the robot take in from the environment? We're going to have something that's much more powerful than the things we have at present, much closer to the capability of the human eye, especially. (It will be) different from the human eye, but (it will have) those powerful kinds of capabilities to pick out relevant parts of a display, home in on them, get high resolution on little fragments of the display or scan it more broadly.

"We can build cameras, but, having taken the picture, extracting information from the picture is a real tough job. The kinds of techniques and approaches that the artificial intelligence community has developed over the past 25 years may play a very large role on the sensory side of robotics. But that remains to be proved. It's not clear yet what kinds of things will work in terms of the interpretation of sensory information. The limits there are software limits."

Even the hardware limits Simon sees are tinged with AI applications.

"The main hardware limits today are on the motor side. They're limits on building things that can have the delicacy and gentleness of the human motor system, that don't have so much inertia, that can pick up an egg. There, a lot of mechanical engineering is being done, (but) there still is the problem of feedback from the sensors and flexible control. So you may still need kinds of control mechansims which are not in the purview of control theory today."

Robotic Possibilities and Limitations. Certainly, the interpretation of sensory information is an important area in AI research today, but there is one area in which AI can make a significant contribution in robotics right now—planning. "Given that the robot is faced with some kind of a problem, with something it has to accomplish, the thinking through of a plan of action that has a chance of accomplishing that is the biggest contribution AI can make right now," says Simon.

"It's easy to see, even at present, how you can build AI programs that address those problems, an example being the 'Shakey' robot out at SRI a couple of years ago. It had fairly primitive abilities to move around in its environment, although it could. But it could think through, it could plan through, what it had to do before it launched into action. It had ways of doing means-ends analysis. 'I want to get there, and I am here. What are some of the things that I can do about it? If doing that gets me some other place, then where do I go from there?'"

In a famous example, "Shakey" was told to remove a block from a platform. To do that, it had to move a ramp to the platform, climb the ramp to get up on the platform, then push the block off. It planned those actions, then performed them.

A significant advantage to having a robot with some planning ability is that instructions to the robot can be simplified. The information content of a single instruction can be substantially more than that in the instructions which are currently used.

If that is what AI can do today, what can we expect it to do for robotics 25 to 50 years from now? "It's very easy to predict that we will have come a long way," Simon says with a laugh. Gesturing toward his window, outside of which a man is operating a large earth-mover, he says, "Maybe within that time span you're talking about automatic bulldozers."

Will domestic robots be as ubiquitous and useful 25 to 50 years from now as home computers are today? Certainly, there will be more automation in home appliances, Simon answers, but there are certain inherent limitations. "Vacuum cleaners? That's a way off because that really requires a great deal of flexibility in moving around an unruly environment. That's the toughest aspect of the job."

While Simon talks about possibilities, he does not neglect limitations. Whether the new robots of a generation from now are automatic bulldozers or sophisticated factory-based

robots, there will always be new technologies offering new information for robots to use. "Physicists are great at devising systems that can detect all kinds of radiation, all kinds of pressure, all kinds of this-or-that. That's not a serious bottleneck problem. The serious bottleneck problem is the next step of how you make coherent interpretations of those and know what kind of a world they're describing."

Programs which analyze that information may be based on theories containing models of the robot's world, but in robotics, unlike most other engineering disciplines, bad theories will not necessarily cause you serious problems. Bad theories can be corrected by good artificial intelligence.

As Simon puts it, "One of the things that makes robotics different from other aspects of AI is you don't have to believe your theories because you're always getting information from the real world that allows you to correct them. All you require is a system that doesn't do something disastrous before the correcting information comes in."

Robotics and Learning. For humans, learning is essential to effective functioning. Learning will also be important to the robots of the future, but in a different way. "In one important respect, you would expect learning to be less central to robotics than it is to human life," Simon notes. "That is, once you have a good program, you can stuff it in any computer that happens to be around. You can make a chip to implement that program. In a human being, the only way we know to implement a program is to send people to school. Sometimes that works and sometimes that doesn't, and it takes a long time. In the human case, there would have to be learning; in the robotics case, you simply stuff a program you already know about into the thing, and off it goes.

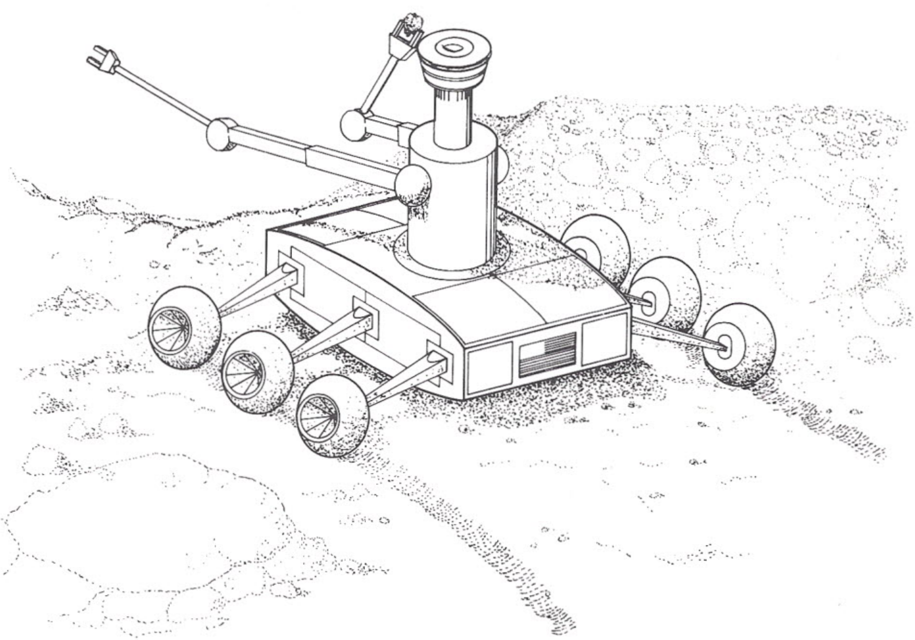
"Nevertheless, there are important realms where learning will probably be crucial. If some of our robotic systems are expert systems—they have a tremendous amount of knowledge about some subject matter—and that knowledge needs to get revised and updated and improved, either on the basis of the robot's own experience or on the basis of accumulation of general human knowledge, it may turn out to be easier to teach new things to a robot than to reprogram it. Because to reprogram it, you have to really understand the structure of the program.

"The great thing about human learning is that we don't have to know the structure of how things are stored now—it causes a lot of trouble that we don't—in order to add new things to the store. And if we get systems that are so complex that nobody, including the system itself, really understands how things are organized in detail inside, maybe the only way of revising that system will be (for it) to learn.

"I think there already is interest in learning. Suppose you were trying to get a nontethered underwater vehicle to do something sensible about the obstructions it encountered. Well, if it were an expert, it might be able to make inferences about what those obstructions were and what to do about them. One could conceive of robotics applications where you would really want an expert as part of the system."

One could, indeed. Imagine a robot planetary probe. If it had to send information back to earth for expert analysis, the round trip for the radio signal, travelling at the speed of light, would take minutes or hours. Trying to control such a robot would be like pushing on a rope.

Simon recalls a similar study of humans trying to control vehicles with delayed responses to steering. "There's been a lot of interest in steering big oil tankers into harbors. When you're steering a ship, there's a very sizeable lag after you turn the rudder before there's any noticeable response to the ship. This turns out to be a fantastically hard job for a person to learn to control a system with a delayed response." An expert system



Taking Simon at his word that "(o)ne could conceive of robotics applications where you would really want an expert as part of the system," artist Gordon Wenneker developed this conception of a rolling/walking robot planetary explorer with artificial intelligence. The robot is examining a rock which it has picked up. For this robot, navigation and movement controlled from Earth would be exceedingly slow due to data bandwidth limitations and the time to transmit information between the robot and an earthbound controller. However, if the robot were equipped with planning capabilities and expert knowledge for interpreting images of its surroundings, it could navigate successfully and transmit information about items which its programs identify as interesting.

at the controls of a tanker or a robotic planetary explorer is an interesting concept.

The Robotic Environment. Whenever a manufacturing company considers installing robots in its factory, it must consider the plant's layout. Much more so than a human worker, a robot needs a structured environment. Even robots with vision require controlled presentation of parts; the parts-in-a-bin problem has not yet been solved. Artificial intelligence will enable robots to adapt to a less orderly environment, but how much so? And will that adaptability have an economic advantage? Simon found the questions interesting.

Turning again to the window, he replied, "It's nontrivial for that guy out there digging to know what he's digging at a given moment, just having a plan to know what the hole should look like eventually. You could have all sorts of devices mounted on the buildings here which would automatically give bearings and control that thing much better than that human operator could do. But what he's got going for him is the ability to see where that dirt is lying in the irregular hole down there and a whole lot of things like that.

"We are going to gradually and not too slowly progress in the direction of being able to build 'beasties' that can live in fairly unstructured environments. And that's why the sensory and motor end of these things is so important. I expect to see steady progress being made, but I think we've got a long way to go."

As to the economic advantages of an unstructured environment, Simon commented, "It was a great discovery a long time ago that the best way to operate on natural materials and natural environments is not to operate on them at all, but to transform them into controlled environments and controlled materials. The first thing any manufacturer does with any natural raw material is to purify it, homogenize it."

After citing examples of the transformation of cotton bolls into cloth and of iron ore into steel, Simon described an example of a controlled environment, "a great advance in drilling engine blocks. They used to have a drill press. They'd first position the block very carefully, drill a hole, move the block very carefully, drill a hole—well, the whole cost was in the calibration, the positioning. You build a drill press with six heads, and all of the calibration is built once and for all into that head. You still have to place the block there, but the accuracy you have to do so is an order of magnitude less than the accuracy at which those holes have to be bored in relation to each other.

"So you get all of the information into the system, and then the operations don't have to process any information at all. Well, that trick is not going to go out of fashion just because we can produce robots. It still, in most cases, is going to be cheaper to grind up the garbage and put it down the drain than it is to robotize garbage collection. That's always going to be the economic competitor.

"Now there are some places we can't do that. If you're actually gonna build a new building, you gotta dig a hole in the earth! And the earth is the way it is." In other words, as long as you can control the environment, you are better off, but there are certain jobs in which you can't. It is those jobs which will benefit most from advances in applied AI.

Brute Force and Sly Tricks. Because of their perfect recall and the ability to do brute-force analyses and lengthy searches, computers have many advantages over the human mind. On the other hand, the human mind has an organization far superior to the most sophisticated modern computer "architectures." In computerese, a human has an "associative" and "content-addressable" memory.

A current controversy in AI circles is whether robotics has more to gain by taking advantage of the brute-force capabilities of computers or by trying to incorporate models of human thought processes. Simon

takes a middle ground here.

"I think the answer is some of both," he says. "The problem spaces in which you have to operate on the problems of interest are so enormous that you're not going to get by just with brute force. You're going to have to borrow all kinds of heuristics and sly tricks from the way human beings do it. And that's been the history of AI."

Looking to the future, Simon says, "I think you will find important AI ideas built into these systems and essential to them, although you will also take advantage of the fact that you've got a lot of cheap brute force. You'll have your cake and eat it, too, in a way."

Acceptance in Society. During his career, Simon has had the opportunity to observe first-hand the reactions of people to computers and robotics. He perceives a change in attitude. A few years ago, he would often inject the following idea into conversations:

"Suppose we had a race of robots which could be raised with humans. They were exactly like humans with one important difference—they were less subject to mental and physical disease. They were, of course, made of metal or whatever, but in a way that they were cuddly enough.

"Now we're going to have a referendum. We want to transmit our human culture to future generations. Are we going to select these creatures to transmit the culture?"

One evening, Simon made the mistake of answering his own question. He told his hostess, "I don't know how I would vote because voting against the robots at that point almost sounds like a form of race prejudice." That remark almost cost him his dinner!

Simon hasn't tried that ice breaker recently, but he suspects that it wouldn't cause him as much trouble as it once did. "My feeling is that the edge is off the fear a little bit with respect to computers for most people. Or I think probably a more accurate way to put it is there are probably fewer people who get creepy feelings when you mention computers than there were a few years ago.... I don't sense as extensive a sharp worry as I did a few years ago."

Simon Sums Up. Discussing his decision-making ideas for which he won the Nobel Prize, Simon says, "Part of the problem of doing good economic research is to find ways of relating theories to information. A major part of my concern with decision-making in economics was to revise economic theories of decision-making to take account of information-processing limitations on the decision makers."

That statement brings him directly to the way AI is applied in robotics. "That's the central theoretical problem we're dealing with in all of this AI. It's not how, in principle, do you solve a problem, but how, in practice, do you solve a problem." □

PATENT PROBE
DRIVERLESS VEHICLE AUTOGUIDE

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The fictional robot and the factory robot have one principal anatomical difference. The R2-D2s of the fictional world, without exception, have some type of ambulatory mechanism. Modern industrial robots, on the other hand, are rooted to one spot in their working environments.

This stay-put design is not always dictated by the application. Moving about requires the ability to sense and interpret the make-up of the environment. Humans navigate by sight, sound, and touch. One or more of these senses would be useful in the design of an ambulatory robot.

Such an ambulatory robot design is described in patent number 4,328,545, entitled "Driverless Vehicle Autoguide by Light Signals and Two Directional Detectors." The automatically guided unmanned vehicle was invented by James R. Halsall, Michael H. E. Larcombe, James R. Robertson, and Mark A. M. Rogers. The patent is owned by Imperial Chemical Industries Limited of London, England.

The concept of a driverless, robot vehicle is not new. Such vehicles are commonly used in automated warehouses. These vehicles, however, are guided along predetermined paths either by sensing wires embedded in the floor or by light beams. The invention described in the patent provides a navigation and guidance system which allows the robot to rove about rather than follow fixed paths. The navigation system consists of on-board light-sensitive detectors which respond to light emitted by beacons of known positions.

At least two direction-sensitive light detectors are mounted on the vehicle. Each detector has a photosensitive element and the means to determine the direction of light detected by the element. Two or more beacons are located at fixed stations in the area in which the vehicle will operate. These stations are chosen so that each detector can receive light from at least two beacons. The output from the detectors is fed to an on-board computer. The computer correlates the bearing of the beacons and calculates the position of the vehicle in the work area.

The beacons are best constructed from constant, omnidirectional light sources. For large work areas, the beacons may be generated as a collimated beam which is swept in a horizontal circle. Infrared and ultraviolet light sources can be used, but the inventors recommend the use of

The illustrations in Patent Probe are reproductions of diagrams in the original patent documents.

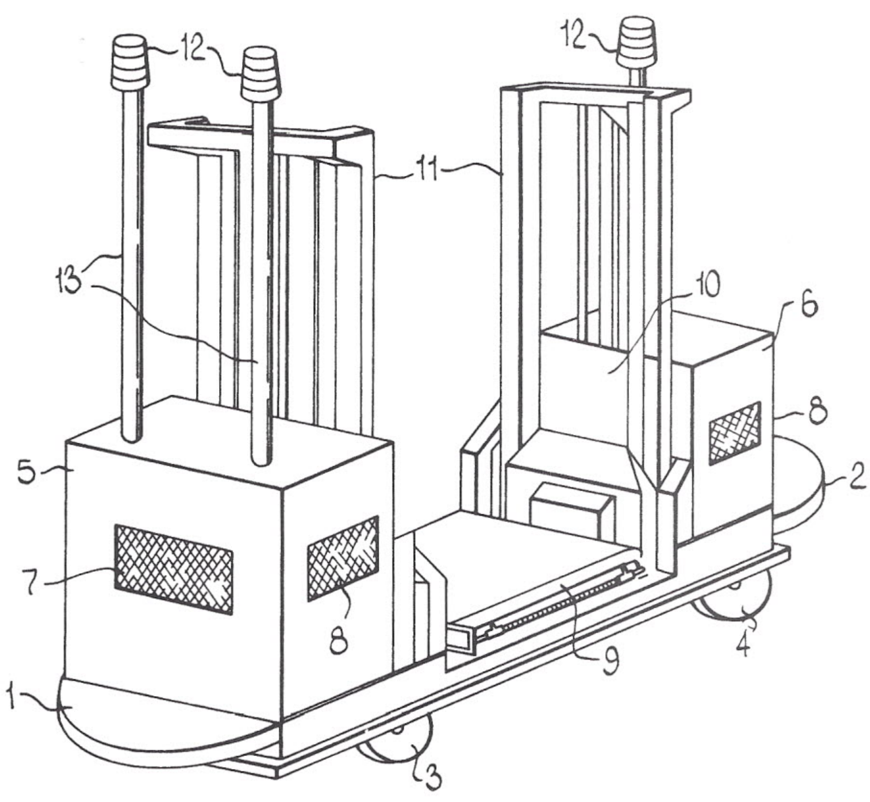

Figure 1. An unmanned vehicle with positioning control.

visible light to simplify system testing and maintenance.

The navigation system is based on the geometry of the direction of the observed beacons. As such, it does not depend on knowing the speed of light or the time taken for light to travel from the beacon as radar requires.

Each detector has a photosensitive element and the ability to rotate the element so it can receive light from each direction in turn. The element is mounted behind a vertical slit aperture to restrict the angle of view of the element. The means to rotate the element includes an angle encoder, which produces a binary output in Gray code. The output of the photosensitive element and the angle encoder are interpreted by an on-board computer.

Two on-board detectors are sufficient to determine the vehicle location under most vehicle orientations. Limiting the number of detectors to two reduces the number of components required and simplifies the required data processing.

If the vehicle becomes positioned so that the detectors and one beacon are all in a line, position calculation is imprecise. One solution proposed in the patent is to have the computer issue instructions to turn the vehicle sufficiently to again establish a triangular position with respect to the beacon. A proposed alternative is to have three detectors rather than two. If the two in use become collinear with a beacon, the third is used with one of the other two to resolve the position.

The known position of the beacons and the position of the detectors on the vehicle are enough to calculate the vehicle's orientation and position in the work area. The distance between the detectors and the beacons is easily calculated by using the Law of Sines. Strictly speaking, simple geometric calculations are only correct when the vehicle is stationary. Since the photosensitive elements are swept in a circle, the light from any one beacon is not detected by both detectors simultaneously. If the vehicle is moving, its motion can be resolved into two components—one

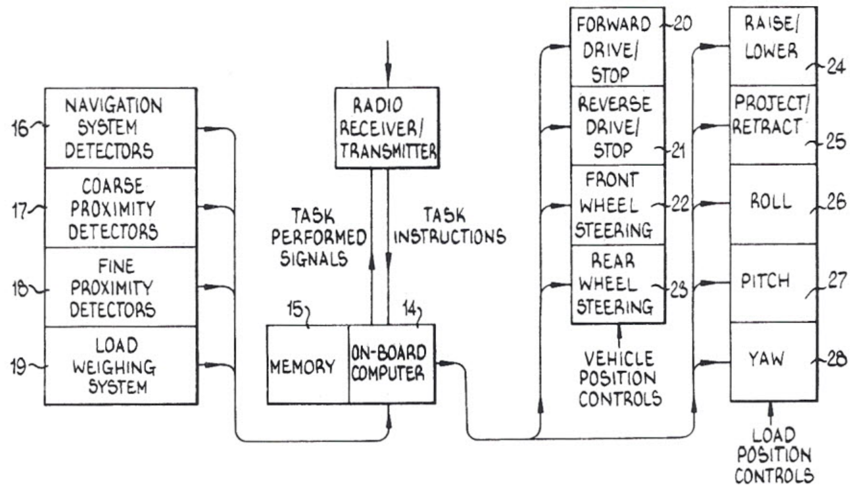

Figure 2. A block diagram of the computer control system.

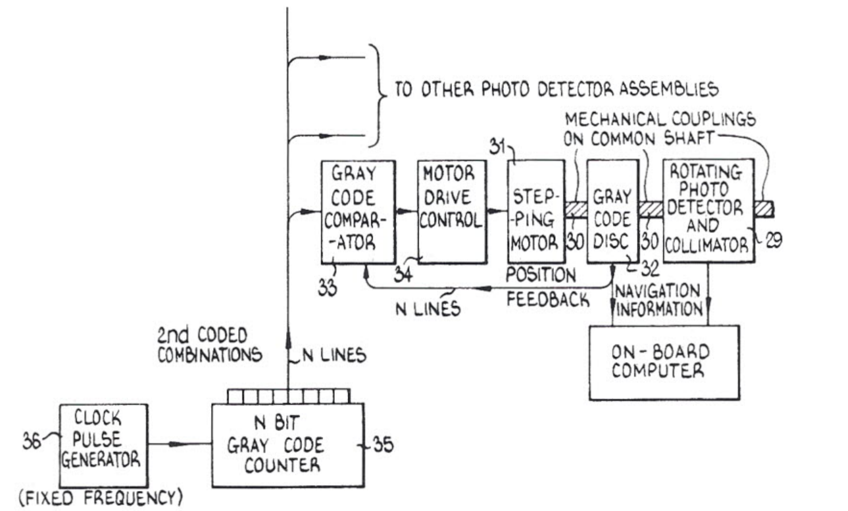

Figure 3. Block diagram of the photodetector system used to position the unmanned vehicle.

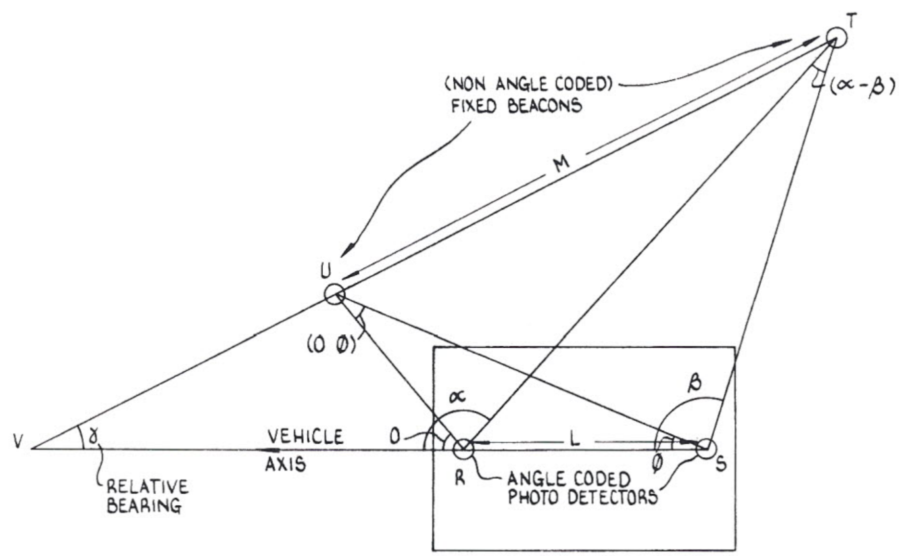

Figure 4. The geometric arrangements used to compute the vehicle's position.

parallel and one perpendicular to the direction of the light received from the beacon. These velocities can be used to calculate a correction value, which may be applied to the calculation of beacon distance.

For low speeds, this correction value is not important. As the speed of the vehicle approaches the speed of rotation of the detectors, the correction value becomes important.

The construction of the robot vehicle preferred by the inventors has four wheels steered by the two front wheels. For close maneuvering, such as the narrow aisles between warehouse racks, limited steering of the two rear wheels is provided.

In applications in which more than one vehicle is operated, each vehicle is fitted with collision avoidance sensors. These might include sonar, radar, or tactile devices and aid in preventing collision with other vehicles or with stationary objects. When a potential collision hazard is detected, the vehicle either halts or calculates an alternative, collision-free route.

As shown in figure 1, the front wheels (3) are fitted with the main steering controls, while the rear wheels (4) also can be steered. In addition to the on-board computer, a radio link with a supervisory computer not on the vehicle is provided. Panels (7 and 8) on the front and sides of the robot contain proximity sensors —either tactile, sonar, or radar. A load-carrying platform (9) may be raised and projected sideways. The navigation detectors (12) are mounted on masts (13) to provide a clear view of the beacons.

Figure 2 shows a block diagram of the computer control system. A remote supervisor computer transmits instructions to the robot vehicle via a radio link. The task instructions typically specify a location from which a load is to be picked up and a desired destination for the load. These instructions provide one set of inputs for the on-board computer and are stored in the computer's memory. A map of the work area is also stored in memory.

Additional inputs come from the navigational detectors, coarse and fine proximity detectors, and load weight sensors. The computer uses these inputs to calculate a collision-free path to the load it is to pick up. On arrival at the load's location, pickup is accomplished by the load position controls operated by the on-board computer.

A collision-free path is calculated to the load's destination. On arrival at the desired location, the vehicle stops and sets down the load. Once the task is completed, a signal is sent to the supervisor computer via the radio link.

The photodetector used in the navigation system is shown in block diagram in figure 3. A collimated photodetector (29) is coupled to a stepping motor (31) and a Gray code angle encoder (32). The rotation of each detector is synchronized by comparing the output from a Gray code counter with the output from respective Gray code angle encoders. Any difference is detected and eliminated by causing the stepping motor of the detector to speed up or slow down.

Figure 4 shows the geometry used to compute the vehicle's position. T and U are two beacons located at known positions a distance, M, apart. The location of the robot is calculated by applying the Law of Sines to triangles RST, RSU, UTS, and URS.

The relative bearing angle, gamma, is calculated by angle comparison or by applying Freudenstein's equation for a four-bar linkage as described in Transactions of the American Society of Mechanical Engineers, August, 1955, pages 853-861.

A copy of Patent 4,328,545 is available from the U.S. Patent and Trademark Office for $1.00. Orders should be sent with payment to: Commissioner of Patents and Trademarks, Washington, D.C., 20231. □

LAMBERTON ROBOTS

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The world's largest, fully reprogrammable, multi-axis precision industrial robot, recently installed at the Cameron Iron Works in Livingston, Scotland, is already demonstrating productivity gains, materials-handling improvements, and significant materials savings.

Designed and manufactured by Lamberton Robotics Ltd., the robot is the first of a new range of heavy-duty robots designed to survive in the most hostile industrial environments. Lamberton's "Scobott" line handles weights up to 2800 pounds at furnace temperatures and in dust, fumes, and potentially inflammable vapors. The robots operate at high speeds to accuracies of plus or minus two thousandths of an inch.

The Scobott line carries price tags ranging between $130,000 and $260,000. It is targeted for heavy engineering, process industries, the nuclear power industry, and medium-heavy mechanical engineering.

The model in place at Cameron Iron Works is "Scobott 700" (see photo 1). Fifteen feet high, with a lifting capacity of 1550 pounds and a reach of 11.5 feet, the robot is mid-range in Lamberton's new line. When fully installed at Cameron, Scobott 700's primary application will be to place batches of reheated forging blanks weighing between 110 and 1550 pounds into position within the plant's forging presses.

The articulated arm robot has a guaranteed accuracy of plus or minus 30 thousandths of an inch. It has a maximum work piece velocity of 350

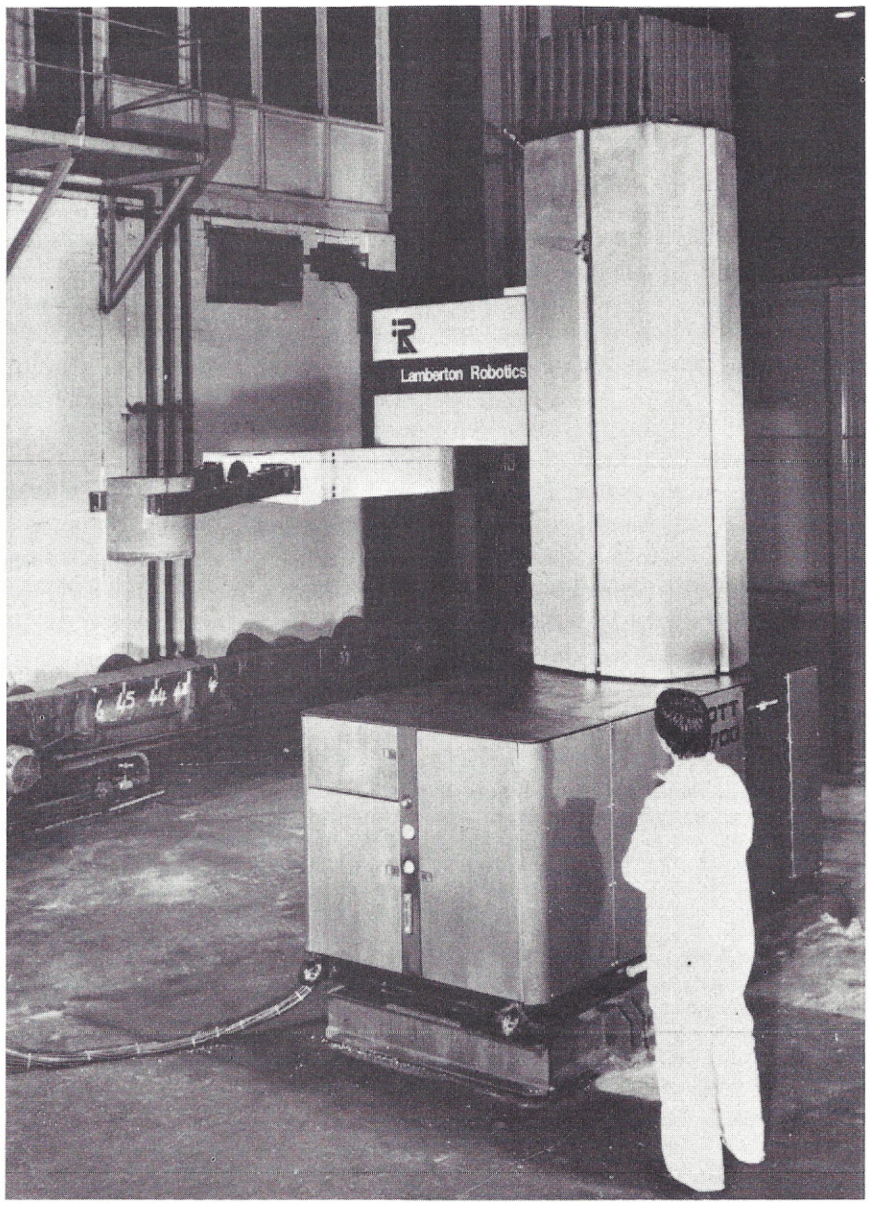

Photo 1. Scobott 700, first in a new line of heavy-duty robots from Lamberton Robotics, has a handling capacity of 1500 pounds. Other robots in the Scobott line can handle approximately 2600 pounds.

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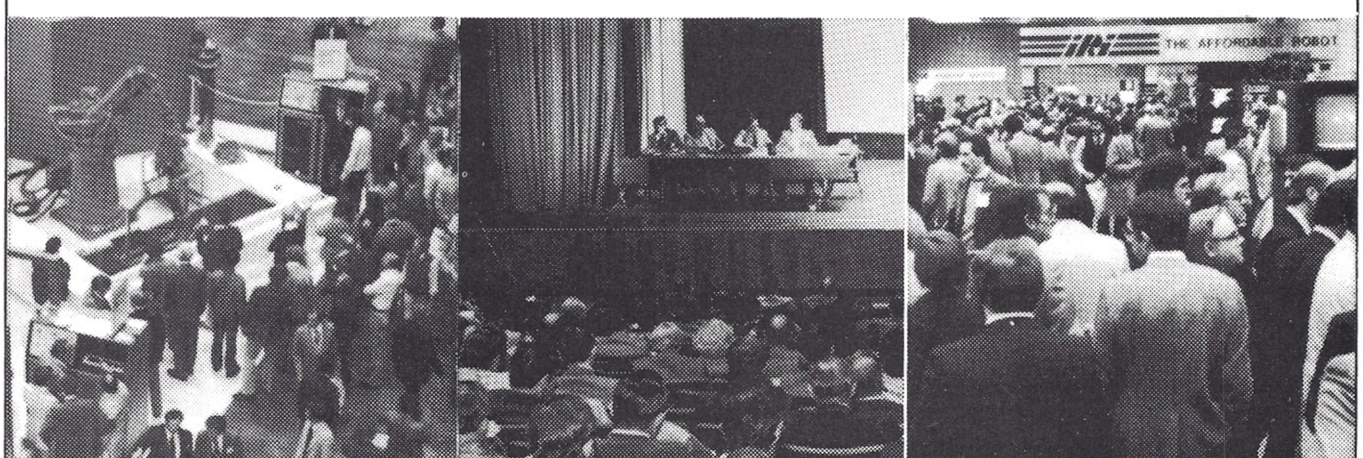

CIRCLE 22

feet per minute. In trials at Cameron the robot achieved consistent placings of between 2 thousandths and 5 thousandths of an inch within a cycle time of around 50 seconds.

Livingston's 30,000 ton press, photo 2, is the world's largest multi-run press. Two 6000 ton side rams complement the main forging vertical presses. The operation is served by both box and rotary preheat furnaces adjacent to the press shop. Cameron's products range from pipe extrusion, used mainly for nuclear engineering, to aerospace components, to pipeline ball valves.

Two years ago, Cameron Iron identified a need for a heavy-duty robot capable of operating in the harsh environment of their forge. It had to cope with the new generation of powder technology materials specified in aerospace engineering.

The use of new, high-heat-resistant alloys using powder technology in key components in jet engines resulted in a need for new forging techniques. Forging temperature of the blanks is critical and requires heated dies and accurate placement to prevent distortion during forging.

This new operation is impossible without automatic loading, since manual placement cannot produce better than one-inch accuracy. Manual methods consist of a five-

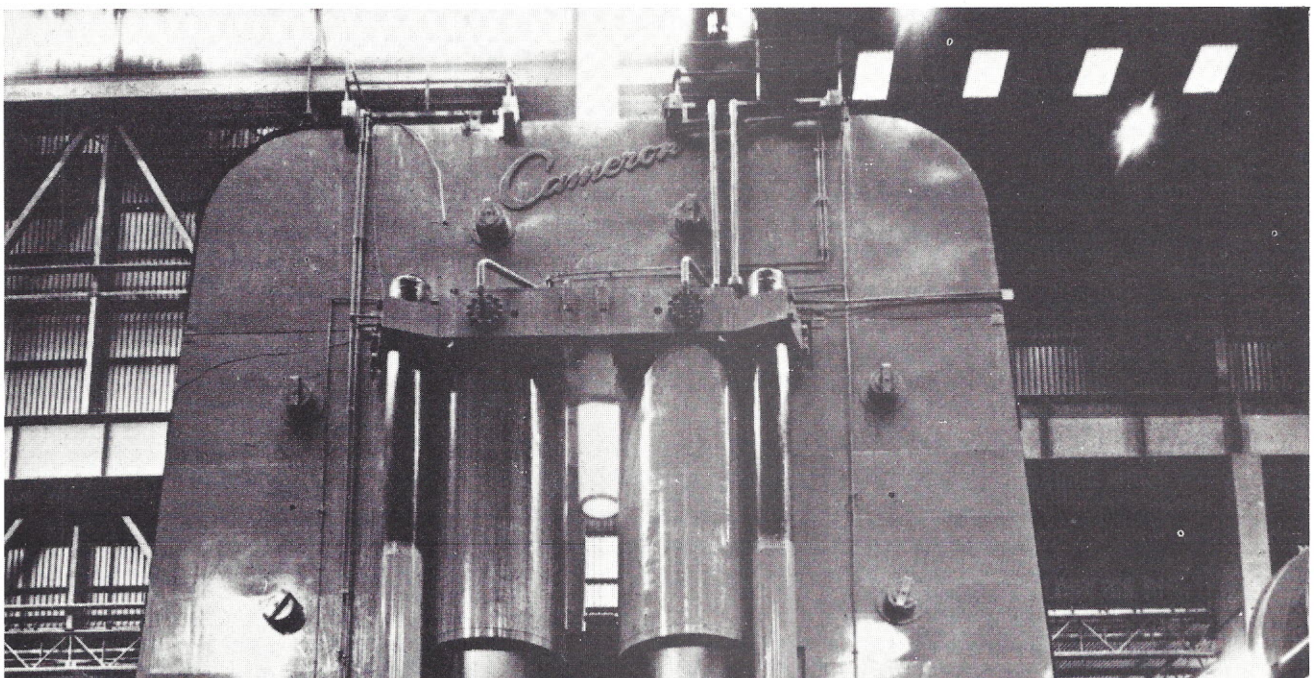

Photo 2. Cameron Iron Works' 30,000 ton press is one of the largest in the world.

person team, protected by silver coated 1300-degree Celsius heat-resistant suits, employing crow bars to lift "blanks" into the forge. Even with this procedure, the placement is accurate only to one fourth of an inch. The time involved could mean that the blank temperature falls below the critical temperature window.

While Cameron faced the dilemma of automating, Lamberton Robotics initiated the design for its Scobott line of heavy-duty precision robots.

Lamberton Robotics of Coatbridge, Scotland is a specialist offshoot of a 100-year-old parent company, Lamberton & Co. Lamberton Robotics was set up to develop the new robot as an extension to its existing range of telechiric manual and programmable manipulators.

Cameron and Lamberton worked together in developing the Scobott 700 robot, which Lamberton believes has wide-scale applications in heavy engineering, process industries, nuclear research, and mechanical handling systems, where extended reach with accuracy is essential in hostile environments.

Trials within the Cameron plant show that the robot performs well within the tolerance specifications. "From what we have found so far, its capabilities were underrated," Cameron's project manager, Grant Webster, claims. "It is capable of handling considerably more weight than its rated capacity and it is extremely sensitive."

Even more importantly, the trials show that the robot lived up to the productivity gains forecast for the automated procedure. "For all the smaller forgings, the robot will cut the manpower needed in the forge loading area. Instead of a five-man crew, there will be a robot operator and probably two more on the handling system from furnace to robot," Webster says.

"The productivity gains will come more from the cycle time possible with the robot—typically 50 to 60 seconds for turbine discs—and from savings on material.

"With some of the more expensive alloys, we can have $1 million worth of material in the furnace at one time. At present we have to put more material on the blank to cover the positioning problem. With accurate positioning—as supplied by Scobott—we could save 25 pounds on a 600 pound blank at the very least. That represents a great deal of saving.

"Taken against the cost, the savings will give us a very short payback time, and we have the advantage of being able to take on new work which cannot be done any other way."

Lamberton also solved an additional problem. "While we had identified a definite need for automation on one particular process, we are basically a jobbing shop," Cameron's general manager, Walter Campbell, explains. "The problem for us was to justify a full robot for a range of products of various sizes and weights.

"There was also the additional problem of the layout of the forge with its two presses side by side which could not be fed from a fixed

robot. It meant we had to specify a demountable system which could be moved quickly." To solve this dilemma, Lamberton devised a system which could be moved from one forge to the other within 20 minutes.

Lamberton Robotics' response to this problem, as well as to the whole development of the Scobott line, is what might be expected of a company known as an innovator in heavy engineering equipment since the 1880s. The company has earned a string of firsts in engineering, ranging from steam engine development to computer-controlled strip steel line chopping. In the late 1970s, they developed a range of manual and programmable guidance manipulators.

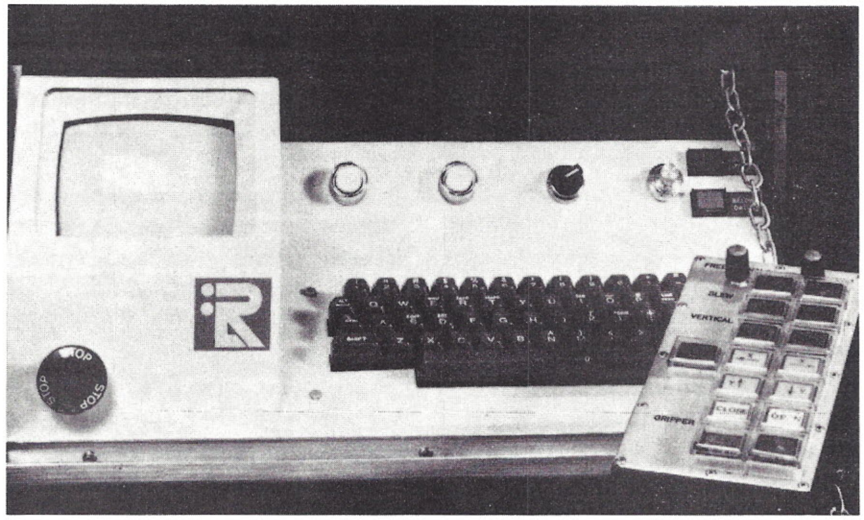

Photo 3. The Scobott robots are programmed using both the push-button "teach box" and the keyboard display system.

The next step was to move into fully programmable robots, which led to the establishment of Lamberton Robotics, designed to bring together expertise in heavy engineering, hydraulics, electronics control systems, and computer aided manufacturing techniques.

Each model is powered by servo-controlled hydraulic motors in three or four axes, with further degrees of wrist freedom available. Microprocessor control is based on an Intel 8080 system designed for use by nonspecialists. The system is easy to program because of its simple drive-and-teach method.

All models are based on two modules—a compact base unit about 39 inches square, surmounted by a solidly encased vertical column mounted on a slewing ring, to give 360-degree movement if required. Straight or articulated arms, capable of up or down movement, can be mounted on the vertical column.

The straight arm version is preferable where very high speeds—up to 980 feet per minute—are needed into and out of the working area. Alternatively, the articulated arm version provides a long reach and a large working volume, with the joint close to the working area especially well sealed. The articulated arm can move in straight lines under computer control, but the operating speed is limited to 350 feet per minute.

With robots of this size, it is impracticable to supply a generalized wrist motion, but at least six degrees of wrist freedom can be programmed once the dedicated end effector has been specified. Any attempt to provide universally applicable tooling would result in overly complicated attachments for the majority of practical applications.

Standard software has been specifically modified to take into account the requirements peculiar to the control of very large robots. Straight line interpolation, acceleration and velocity control, and a high

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degree of self-monitoring are all built into the system. Using a plug-in "teach box," the robot is taught an operation by being led through its various positions. Critical points in the sequence are recorded in the computer memory by means of a memo button to establish the outline program. Microprocessor and electronic hardware is usually located in a free-standing unit, but in Cameron's case, it is incorporated in the base unit, primarily because the robot is demountable.

By means of a keyboard, points from the outline program are precisely defined with respect to speed, acceleration, (this capability is unusual in robot programming where acceleration is usually a fixed value), form of movement (polar, Cartesian, high or low accuracy positioning), type of grip, and time delays. The control system includes a number of additional features:

- Ten programmable registers. These can be related to the program or an external input. In a flexible manufacturing system, for example, decisions might have to be made about which machine tool to serve next in relation to what has already been produced.
- Twenty programmable inputs, outputs, and interlocks. In a machining center, the robot will control surrounding equipment and may communicate with other robots.
- Additional flexibility. It is possible to skip to another part of the program if necessitated by external factors. In a flexible manufacturing system, it is possible to control the program or programs stored in the main memory from a mainframe computer.

The programming procedure from outline to details employs a very simple, limited, and specific series of commands. It enables rapid programming and insures precise repetition of significant points in the sequence—a major advantage in complicated movement patterns. In practice, speed, acceleration, and type of movement tend to be changed frequently throughout a sequence as experience is gained and patterns are refined to optimum efficiency.

In the case of the Cameron robot, the main memory stores 10 programs of up to 500 movements each, with an additional 100 programs available through an auxiliary floppy disk or tape system.

"A full robot was a logical extension to our experience with manipulators for heavy industry," Bill Goldie, Lamberton's managing director, says. "The more we looked at it, the more we became convinced that there was a gap in the market for a really rugged machine which could stand up to dust, fumes or heat.

"Until now, robots have been used in clean environments and, in general, have been employed in high volume manufacturing areas. Attempts to scale up have not been very successful.

"We started from the opposite end. We had experience in the heaviest and the worst environments and we have now proved that our machines can fill this gap in the market."

Goldie originally estimated sales of about 20 robots a year. Since the robots were launched, however, Lamberton has heard from a wide range of industries outside the heavy steel handling and machining areas initially expected. Inquiries have come from shipbuilding, oil and chemical processing, and even brewing and packing.

"The brewing application really surprised us," Goldie says. "They have the problem of handling and stacking very heavy beer barrels on pallets. They want us to solve the problem of identifying the corner of the pallet for development of a loading pattern. It's an application with a huge potential market.

"All told I am very happy to say that before we have started seriously marketing the system worldwide, we are having to rethink the sales potential.

"The key factor is our machine's ability to survive in real industrial environments. There is just no other machine in the market we are aiming at." □

New Products

General Electric Introduces Fast New Process Robot; Compact, Flexible Controller Has Video Screen

General Electric's P50 robot manipulator arm is particularly adept at arc welding and features a compact controller with a video screen to assist the operator.

The P50 manipulator arm can travel 39.4 inches a second to help reduce cycle time. It has large servo drives to provide more power and smoother operation at extended reach.

The P50 controller features a 9 inch video screen that displays operator prompts and has the ability to combine individual programs into a larger, more complex system of actions. The robot's bubble memory system has a programming capacity of up to 2,000 teach points in up to 256 programs.

The P50 is designed for arc welding, deburring, polishing, grinding, sealing, and assembling applications. Its versatile, multi-joint arm makes it possible for one robot to perform multiple tasks within its work area. Its light weight, only 770 pounds, makes it easy to reposition.

A remote teach box allows the operator to program the robot in Cartesian, cylindrical, or articulated coordinate systems. The robot also has self-diagnosis to detect operator error and sense robot malfunction, thereby increasing quality and safety. The five axis robot has a 22 pound payload capacity and a positioning repeatability of ± 0.008 inch.

For literature and application information, contact: Automation Systems Department, General Electric Company, 1285 Boston Avenue, 33DE, Bridgeport, Connecticut 06602, (203) 382-2876.

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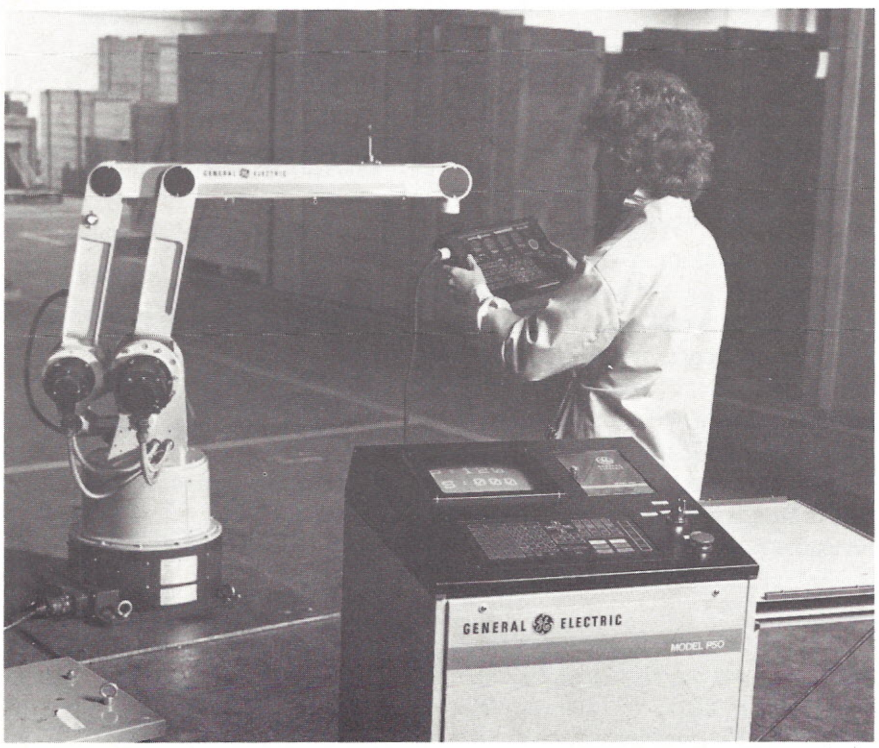
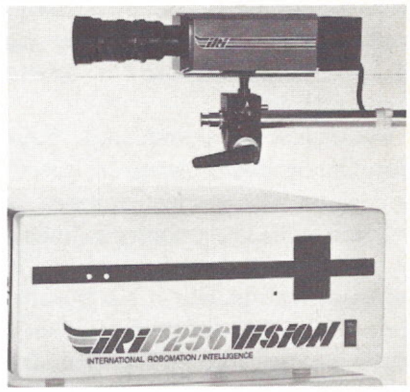


Affordable Gray-Scale Vision System



International Robomation/Intelligence (IRI) has introduced an affordable vision/image analysis system for robotics, which offers a 4-to-1 price and performance breakthrough.

The system features 256 gray levels, 4 frame buffers, a hardware preprocessor, and a built-in, 1 million instructions-per-second host computer, all for \$4,900 in quantity. A 100-to-1 speed-up is possible with the optional 3.25 million pixel-per second hardware coprocessor which provides the capability for real-time processing at television frame rates.

The IRI P256 Vision System consists of an image digitizer and preprocessor, a host computer, an optional hardware coprocessor, and the associated mechanical packaging and power. Off-line program development systems for assembler and higher-level languages are available.

The IRI P256 Vision System evaluation units will be available during the first quarter of 1983. The basic unit price will be \$9,800. Packaged in a 17 inch by 17¾ inch by 7 inch housing and weighing 25 pounds, the IRI P256 can be used on a desk top or rack mounted.

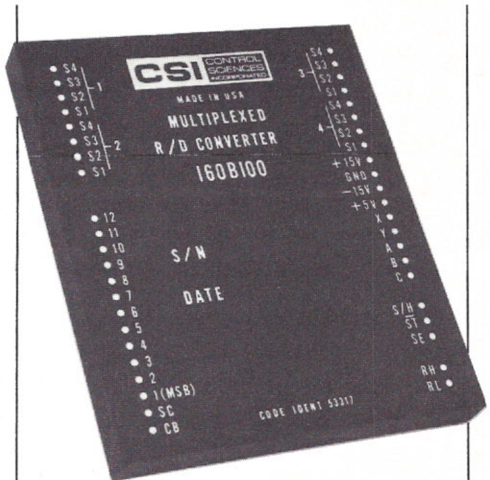
For further information, contact: David R. Davidson, International Robomation/Intelligence, 2281 Las Palmas Drive, Carlsbad, California 92008, (619) 438-4424.

CIRCLE 31

Ultra Low-Cost R/D Targets Robotics

The 160B series of resolver-to-digital converters offers up to a 4-to-1 reduction in the cost of angle or distance encoding in robotic/machine tool applications. An expanded converter can cost less than $50 per axis (100 quantity). Designers may now project total monitoring costs at $100 per axis, including a brushless resolver. Additional savings are offered since the circuit board area required for conversion is reduced significantly, enabling many users to eliminate whole circuit boards in existing designs.

The basic unit in the 160B series is a complete, four-channel resolver (or synchro)-to-digital converter in a single, low-profile module. For larger system requirements, additional 4 or 8 channel expansion modules may be added (up to 40 input channels). Devices offer 12-bit resolution, 8.5-minute accuracy, and less than 100-microsecond conversion time.



Resolver (synchro) inputs may be specified from 2.5 to 130 volts rms L-L at operating frequencies from 50 to 5000 Hz. Logic inputs and outputs are TTL/CMOS compatible.

Compared to standard converter modules, a 160B 12-channel R/D converter system would reduce the required circuit board area from over 98 square inches to 24 square inches—a savings of over 75 percent. The same comparison would reduce the cost from $2700 to $865—a savings of 68 percent in unit quantities. Delivery is stock to four weeks for small quantities. Unit pricing (four channels) is $495 (1-9). Contact: Rhod Zimmerman, Control Sciences, Inc., 9601-1 Owensmouth Avenue, Chatsworth, California 91311, (213) 709-5510.

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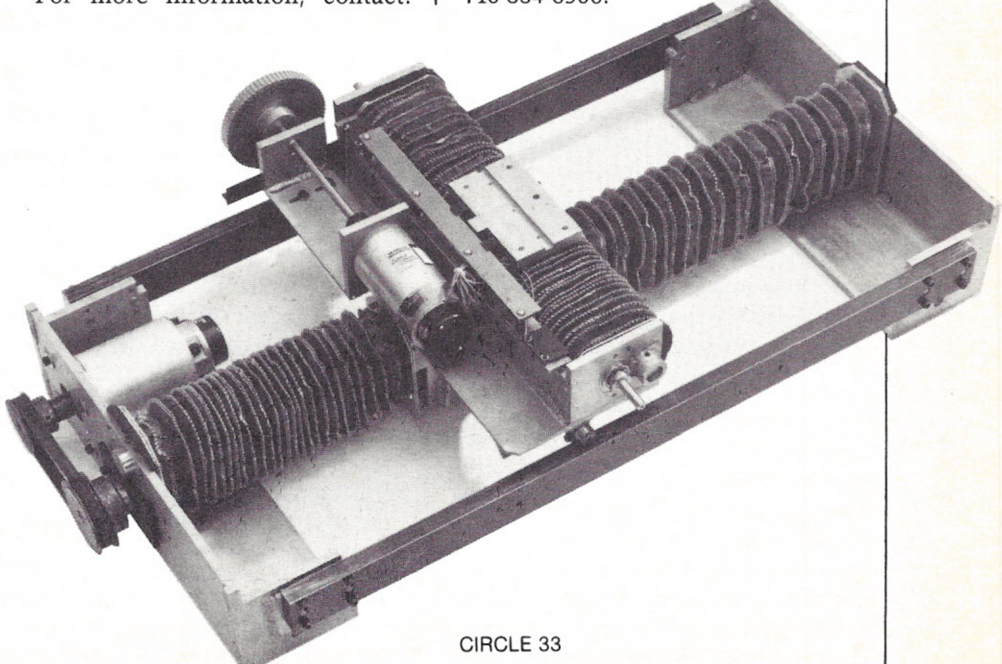
Robotics Positioning Mechanism

Boston Machine Works of Lynn, Massachusetts, has introduced a precision x/y positioning mechanism. The transport and power bridge amplifiers are designed for accurate, high-speed, incremental movement. Boston Machine's positioning system can be controlled easily via any computer I/O port.

The system is ideal for a wide range of industrial applications, including pick and place, sorting, welding, assembly, and adhesive dispensing. Positioning accuracy is achieved by the use of precision drive mechanics combined with Hall-effect calibration switches.

Boston Machine Works' positioning mechanism is available in a variety of different configurations. Variables include: motor type (dc servo or stepper), feedback method (encoder, tachometer, potentiometer), leadscrew drive (standard ball-bushing leadscrew or precision ground leadscrew), range of movement (10 inches by 24 inches standard, with other configurations available), mounting configurations (standard, custom adapter plate, or specialized configurations to meet customer specifications).

For more information, contact: William J. Valles, Boston Machine Works, 17 Willow Street, Lynn, Massachusetts 01903, (617) 593-0200 or toll-free (800) 343-8317/Telex 710-334-6906.



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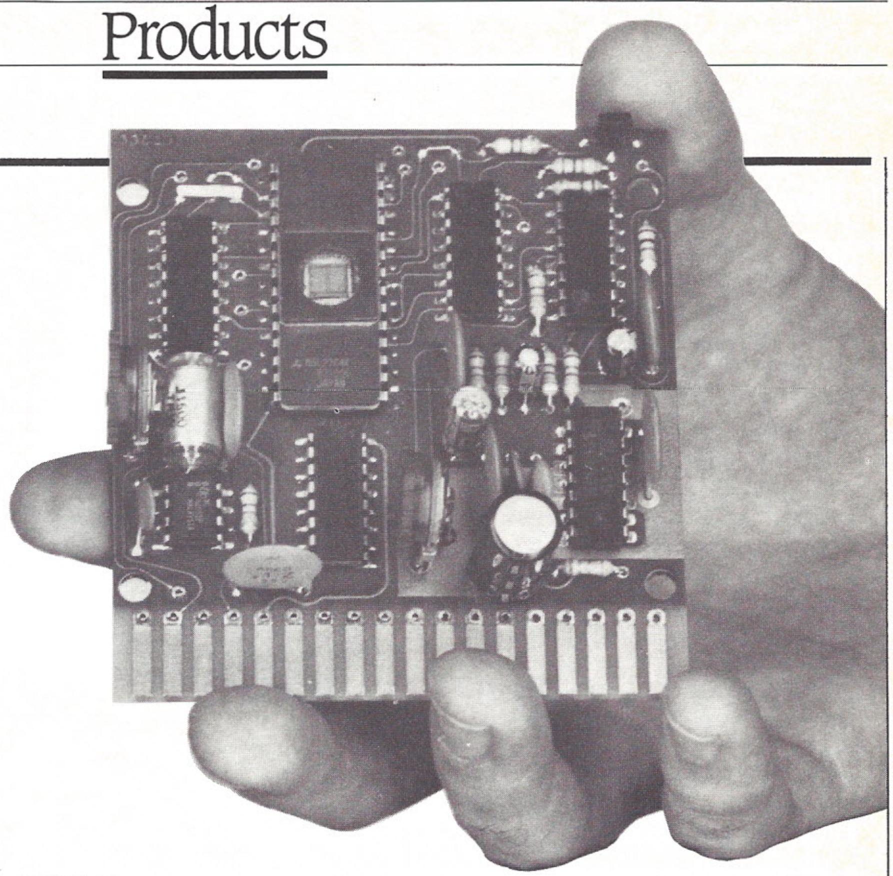
Low-Cost Synthesized Speech



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DataVoice Corporation announces the Cheaptalk (CT) 200 circuit board, a new addition to the popular Cheaptalk line of synthesized speech products.

The CT-200 is a completely self-contained speech synthesizer module that holds up to 3 seconds of speech or sounds. Total playback time may be partitioned into 1, 2, 4, or 8 equal intervals in order to hold multiple words, phrases, or sounds. Multiple boards may be cascaded to achieve longer continuous recordings. The 3 inch by 3.25 inch board is simple to operate, requiring simple switches or TTL control logic. Signals are provided for interfacing with a microprocessor as well. A volume control and 1 watt audio amplifier are included on board but may be bypassed if an external amplifier is desired.

Users may select phrases from a standard vocabulary or order customized boards with messages specific to their applications. Custom encoding costs just $100 and takes only one week. The clear, high-quality human speech can be ordered in any male or female voice. Custom users can specify the emotions, attitudes, or intonations to be conveyed in the voice (for example, friendly, stern, angry).

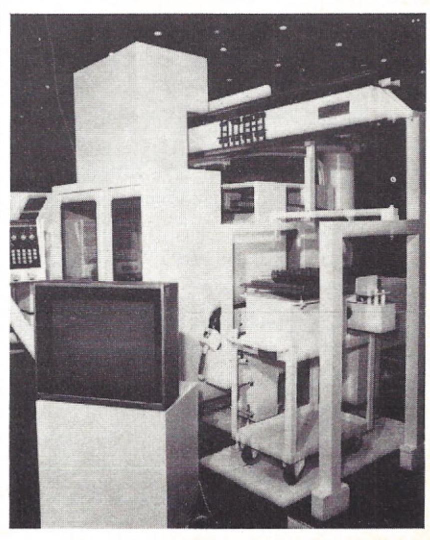
Three TTL-compatible phrase select lines are addressed for multiple-phrase boards. A *start* line initiates speech in the normal mode, but a *continuous* line may be used to achieve a 50 percent duty cycle continuous operation. A *done* line indicates the end of speech and may be used to initiate additional speech boards or delay timers. A factory calibrated clock is included on board. Operating power is +5V at 200mA max for the logic. If the power amplifier is used, an additional +12V at 800mA maximum is needed. Connections are made to an 18-pin trace connector with 0.156 inch contacts.

The CT-200 is ideal for audio operator alarms, prototyping, motor control alarms, audio status for test instrumentation, vehicle operator instruction, and many other OEM and retrofit applications since it is so easy to use. In small quantities, delivery is from stock. Larger quantities may take from four to six weeks. The price is $185 each (1-19 pieces), $68 in OEM quantities. For information contact: Rick Arons, DataVoice Corporation, 2 North LaSalle Street, Suite 1900, Chicago, Illinois 60602, (312) 327-8488.

Tool Changing Robot

A MOBOT System Epsilon Robot performs automatic tool changing on turret lathes. The tools are loaded into a cart in the tool room, and the cart is rolled to the lathe and plugged into the MOBOT. The MOBOT moves the cart in one direction and moves the tool gripper in the cross direction to select tools. An extended MOBOT is available for both tool changing and work piece changing. Other models are available for mill and machining center tool changing, with 100-tool capacity.

For more information, contact MOBOT Corporation, 980 Buenos Avenue, San Diego, California 92110, (714) 275-4300. CIRCLE 35

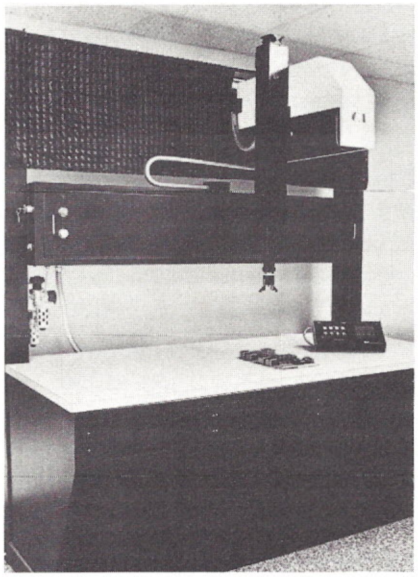


New Products

Robot Speeds Printed Circuit Board Assembly

A new, high-precision, microprocessor-controlled robot has been introduced for use in printed circuit board manufacture. It is the first robot on the market capable of high-speed, automatic placement of non-standard parts, according to the manufacturer, Control Automation, Inc., of Princeton, New Jersey.

The Sembler model CAR-1000 is an all-electric, all-digital robot which utilizes Cartesian geometry and advanced servo control to achieve optimal precision at minimal cost. The Sembler is available with one, two, or three arms and provides precision to ± 0.001 inch. Each arm is capable of coordinated motion in x, y and z axes, plus wrist rotation (theta). The work envelope is 56 inches long, 20 inches deep, and 20 inches high. The robot



wrist is capable of rotation up to ± 180 degrees. Load capacity is 10 pounds.

A major application for the Sembler robot is printed circuit board assembly. The Sembler's precision allows it to handle odd-form factor components, such as transformers, hybrid integrated circuits, and surface-mounted elements. Other applications include material handling and assembly of computer peripherals (keyboards, floppy disks, and so on), electronic motors, and automotive subassemblies such as carburetors.

The Sembler robot can be viewed as a computer peripheral and thus can be controlled from the outside by *any* computer in *any* language, merely by passing keywords in ASCII along RS-232-C serial lines. The standard system includes an external computer (SC-1000) which the user programs in BASIC.

For additional details, contact: Control Automation, Inc., PO Box 2304, Princeton, New Jersey 08540, (609) 799-6026.
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Classified Advertising

Editorial

Continued from page 16

to put the robot into a nonoperational, low-power "sleep" mode, with a transition into an "awake" mode every few seconds. This conserves power while the robot is not actively involved in some task.

An obvious experimental extension of Hero as it is presently designed is to solve the feeding problem. Instead of organic calories, Hero requires joules of electrical energy. The problem, feeding, is the same. If Hero is not in the energy-conserving sleep mode, his batteries will last an hour or so before discharge. (When the batteries get low, Hero's present operating system lets you know with a plaintive bleating of the words "low voltage" until the computer no longer operates.) At present, Hero requires human attention in order to obtain the necessities of existence. In normal use, we operated Hero with his battery charger cable connected. This is like a person in a hospital receiving intravenous nourishment through a direct connection to a supply of predigested chemicals...not exactly conducive to unconstrained mobility.

Who will be the first reader to implement a true feeding strategy for Hero? This project is a combination of software and hardware development. The software of programs to implement a food seeking strategy is not necessarily trivial. The hardware of feeding stations, power transfer connections, and food sensors are other challenging parts of the task.

This, of course, leads into yet another area of engineering improvement which Hero can inspire. Hero at present is primarily an open-loop system with zero feedback from the environment. Sure, the system incorporates sensors, but the use of sensor information in the robot as delivered is minimal. Use and application of the sonar, the motion detector, the light sensor, and the microphone are all pretty much left up to the imagination of Hero's owners.

The inadequacies of open-loop, sensorless operation are made most obvious by a few experiments with Hero's ability to record a motion program. We start with Hero at a point, X, in our office. We proceed to move Hero to point Y in the "learn mode," possibly doing a couple of random direction changes

along the way. Then, still in the learn mode, we move him back to starting point X.

Fine. We now have a program in memory, a sequence of commands to Hero's motors. But this sequence has only a very loose coupling to the reality of the room in which it was performed. An error of a few degrees in placement of the robot body at the start of the path can translate into an error of several tens of degrees, as well as several tens of feet in location after running a course of any complexity. Sufficient complexity is provided by a course involving several tens of feet in linear distance and a small integer number of turns through an absolute total angle of several hundred degrees.

The reasons are simply explained: the boundary conditions of Hero's initialization in a trajectory are not exactly controllable. This is compounded by random errors in traction between the drive wheel and the floor. Traction errors are inherent in any use of a carpeted floor, or in use of uncarpeted floors with apparently minor variations in height.

The solution to this kind of navigational performance is a way to sense absolute position within the geometry of Hero's world. Hero needs what might be called "area navigation" to borrow an aerospace term. An area navigation system is a method of creating an absolute reference for position which can be sensed by the robot's on-board computer. This can be obtained in a number of ways. Using Hero's light sensor, absolute position could be determined reliably (if slowly) by using several beacon lights spread about the room. Similarly, if the room has well-defined walls and objects, the sonar built into Hero could be used to build a map of known space. The important point, though, is that the truly maneuverable mobile robot is one which actively senses its environment. A reliably repeatable pattern of motion is impossible without such an absolute reference method.

Where do we go from here? Hero represents just a first step in the lives of heroes. The idea of domestic pet-like mobile robots is by no means exhausted by a first product. There will be new and improved heroes designed by Heathkit and other companies. In 1975, when the first personal computer attempts were being marketed, these computers for all intents and purposes could not carry out any practical tasks. The Altairs and Sols of 1975-1976 just cannot compare with the personal computers so widely accepted today. Those computers had limited memory, no mass storage, and the same practicality.

Neither can today's Hero provide any immediate benefits that the skeptic could measure. The indirect benefits of learning, exploring, and testing ideas are more than enough to justify this robot's existence. Today, with a mature personal computer industry, skeptics will almost believe "blue sky" talk of the possibilities and benefits of personal computers. Personal computers are a business with in excess of 3 billion dollars in sales.

The Heath Hero-I is a necessary first step towards development of the personal robotics industries of the late 1980s and early 1990s. The experiments done by thousands of individuals with the Heroes of 1983 are a necessary step in the development of that future industry. Tomorrow, thanks to the pioneering products such as Hero, the task of convincing the skeptics of the reality of personal robotics will be much easier. The ultimate market for the consumer robot is, and remains, every human being. The robot as a general-purpose servant of humanity may yet arrive after a few more technological generations. □

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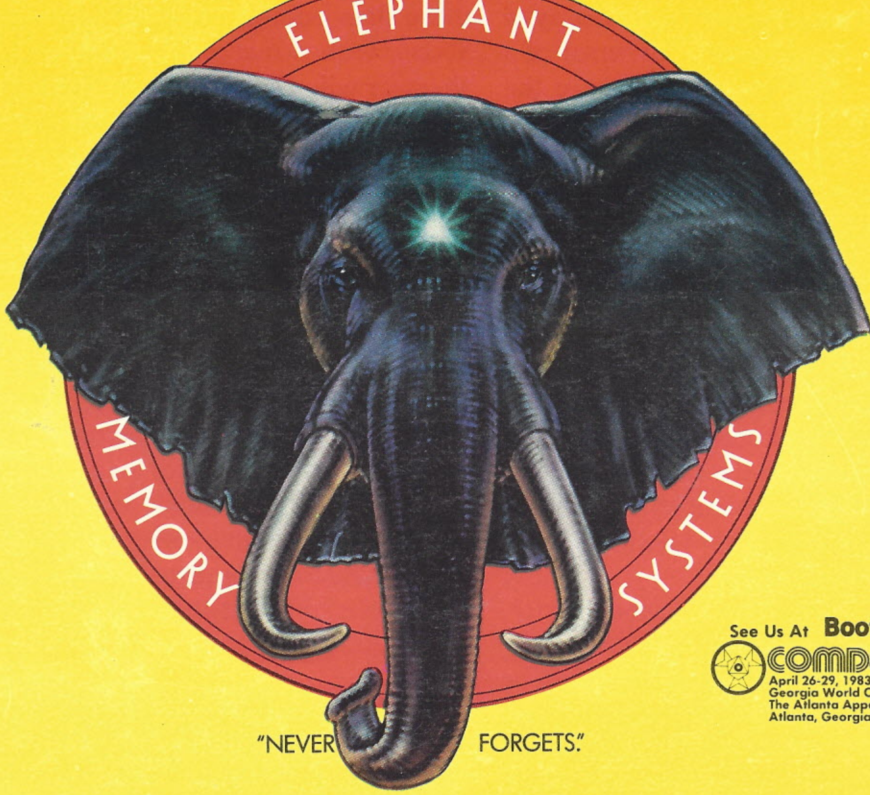

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